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UNIVERSITY OF PENNSYLVANIA

CONTENTS

A Photographic Study of Tremor During Postural Contraction: R. T. SOLLENBERGER 579

Muscle Potentials and Conditioning in the Rat: W. S. HUNTER 611

Human Occipital Brain Potentials as Affected by Intensity-Duration Variables of Visual Stimulation: R. M. CRUIKSHANK 625

A Study of Differential Pitch Sensitivity Relative to Auditory Theory: C. C. IRWIN 642

Relation of Voluntary Motor Pressure Disorganization (Luria) to Two Other Alleged Complex Indicators: L. S. KRAUSE 653

The Effect of Shock at the "Moment of Choice" on the Formation of a Visual Discrimination Habit: C. W. FAIRLIE, JR. 662

Studies in Thermal Sensitivity: I. Adaptation with a Series of Small Circular Stimulators: W. L. JENKINS 670

The Neural Determination of Critical Flicker Frequency: S. H. BARTLEY 678

The Psychological Laboratory at the University of Iowa: C. A. RUCKMICK 687

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A PHOTOGRAPHIC STUDY OF TREMOR DURING POSTURAL CONTRACTION

BY RICHARD TALBOT SOLLENBERGER

University of Virginia

INTRODUCTION

Tremor is the involuntary oscillation of any part of the body. It is due to the alternate contraction and relaxation of certain skeletal muscle groups and their antagonists and is more commonly observed in a voluntarily maintained posture or in a volitional movement of the extremities. The presence of tremor has long been symptomatic of an underlying nervous pathology. Plateau (**37**), in 1867, and subsequently the French clinicians Ferand (**14**), Selice (**39**), Jaubert (**27**), Gougelet (**20**), Saint-Mezard (**38**), and Breillot (**6**), made the first classifications of pathological states in which tremor was a prominent symptom. Representative textbooks of today, by emphasizing tremor as a symptom (Wechsler (**47**) describes tremor as 'the most common of all *abnormal*[1] movements'), lead their readers to the assumption that it occurs only in pathological states.

The fact that tremor is a normal phenomenon has been generally overlooked, and investigations of tremor per se have been relatively few in number. Nor has this reflex been utilized as a possible indicator of normal muscular tonus. It is the purpose of this paper to make a quantitative analysis of the characteristics of normal tremor under specific conditions

[1] Italics ours.

and to determine what effect mental work might have upon peripheral muscular tonus as indicated by changes in the characteristics of tremor.

Historical

Direct experimentation on tremor began with Fernet's (**15**) invention of a method of graphic recording in 1872. He used two tambours, one of which was held between the patient's fingers. This was connected with the recording tambour which supported a writing lever. The lever traced on the conventional smoked drum kymograph. Using this apparatus Fernet found no tremor when the hand was in repose or artificially fixed. However, when the fingers were under weak contraction, or were slightly pressing on the tambour, occasional weak tremors were noticed. Although Fernet did not mention the possibility of a physiological tremor, this is the first instance in which tremor was recorded in the absence of a pathological state. Further graphic recordings in diseased conditions by Debove and Boudet (**11**) in 1880 and Fubini (**18**) in 1886 led to a more or less unanimous description of the rate and amplitude of tremor in certain pathological conditions. Thus Charcot (**8**) in *Lecons sur les Maladies du Systeme Nerveaux* describes hysterical tremor as being "remarkable in its perfect regularity and its constant rhythm. It consists of oscillations of which the number is 5 or less per second . . . , in this regard it is in the middle between slow tremors, for example paralysis agitans, and the vibratory tremors or rapid oscillations of general paralysis." This view was confirmed by later experiments of Dutil (**12**), Dana (**10**), and Le Filliatre (**30**). No startling innovations of method were evolved by these men. Dutil perfected Fernet's original method and Le Filliatre, by using a silk thread attached to the receiving tambour was able to obtain tremor tracings from any part of the body. Dana's contribution was in the use of Dudgeon's sphygmograph.

In 1896 Lamacq (**28**) read a paper before the Congres des Alienistes et Neurologistes de France in which he said that vibratory tremor is as frequently found in normal subjects

as in those suffering from nervous or mental disease. In rejoinder a M. Crocq stated that there is no such thing as normal tremor but in reality Lamacq's "normal" subjects were either neurasthenics or alcoholics! Unfortunately Lamacq gave no description of his apparatus or subjects and neither did Meyer and Parisot (**34**), who had previously concluded that senile tremor is merely an exaggeration of a normal physiological tremor. We see then that among the French clinicians the possibility of a normal physiological tremor is still a debatable question in 1896, but ten years earlier Schäfer (**40**) 1886, in a well-controlled experiment, had shown the existence of such a tremor. He applied the button of a tambour to the opponens pollicis muscle in twenty human subjects. Tremor tracings were recorded when the subject voluntarily contracted his hand. His results showed that the amplitude of the tremor varied from individual to individual yet the rate of vibration varied only within comparatively narrow limits. The average rate of all subjects was 9.8 per second with a variation from 8 to 13 per second. These results coincide with the most recent investigations on tremor (Bousfield (**5**), Travis (**44**), and Binet (**3**)). Schäfer concluded that a prolonged voluntary contraction in man is an incomplete tetanus produced by from 8 to 13 nervous impulses per second. This occurrence of 'normal' tremor was supported by the findings of Wolfenden and Williams (**48**) in 1888, who stated that nervous disorders only increase the amplitude of the normal excursions and thus make them visible to the casual observer. This conclusion was also reached by Peterson (**35**) (**36**) in 1889, who used an Edward's sphygmograph in registering tremor in 26 different diseases. Both Peterson and Wolfenden and Williams agreed that the slower rate observed in some pathological states was due to a fusion of the normal vibration rates.

The presence of a physiological tremor had now been definitely asserted, but there were those who still expressed doubt, as we have noted in the reply to Lamacq. It was Eshner (**13**) who put this doubt to rest. In 1897, Eshner carried out an investigation, the objects of which were to

determine (1) whether or not a demonstrable tremor exists in healthy individuals; (2) whether or not any relation or gradations exist among various kinds of tremor; and (3) whether or not various forms of disease present, as to their tremor, distinguishing characteristics. For this purpose he constructed an instrument which he termed a 'tremograph.' It was in reality an enlarged inverted sphygmograph. An elastic membrane was stretched over a ring. On the under side of the membrane was attached a vertical rod which was joined to a horizontal rod or registering needle by a sliding band. The horizontal rod was fixed a short distance from this junction by a pivot allowing it to move freely in the vertical plane. Any movement of the membrane was transmitted to the registering needle magnified in proportion to the length of the needle. Eshner also calibrated the sensitiveness of his membrane by placing weights on it and noting the height of the registering needle against a prepared scale, thus he was able to obtain the same degree of pressure on the membrane in different experimental sittings. Over a hundred healthy and diseased subjects were used. He definitely recorded tremor in all of his normal subjects. The average rate of tremor in all subjects was 6.7 per second. The fastest rate of 10.7 per second was observed in a healthy individual. The movements were irregular in rhythm and amplitude and the frequency of movements bore an inverse relation to their extent.

Modern investigations of tremor as a normal behavior response date from this classical study by Eshner. Succeeding experiments have been either devoted to checking Eshner's results through the use of different methods or apparatus or to determining the effect of experimental variables upon normal tremor rates.

Busquet (7), using a pivoted steel lever which traced directly on the kymograph and amplified the subjects movements 8 to 1, confirmed the fact that physiological tremor is a constant phenomenon present in all individuals. He also found that cooling of the observed part of the body did not affect the character of the tremor. As late as 1918 Binet's

(**3**) principal conclusion was also that tremor is a normal, constant phenomenon with a rate of 8 oscillations per second; he also found that muscular contraction, physical and mental work increased the amplitude of tremor, as did fear. Individual variations in the amplitude depended upon the emotive coefficient of the individual as determined by cardiac and respiratory reactions to emotional stimuli.

More recently the investigation of tremor has been stimulated by Hill's (**23**) recording of a vibration rate of around 50 a second (1921). Hill used a tambour connected with a hotwire sphygmograph which records the vibration by means of a string galvanometer. That this rate is not an artifact of the apparatus is shown by "(1) different subjects give different rates, (2) the same subjects give the same rates with different tambours, and (3) the vibrations of the tambours are at a different speed."

Travis (**43**) (**44**) constructed two ingenious apparatuses in further investigation of these high tremor frequencies. A carbon button microphone converted finger pressures into a pulsating electric current which was amplified and picked up by an electromagnet telephone receiver connected with a phonelescope. The movements of the phonelescope were recorded on a moving picture film. Pressing the finger or the tongue on the button gave modulated waves, termed 'envelopes,' of 10 to 12 per second, and the records showed that these 'envelopes' were composed of amplitude changes ranging in rate from 300 to 600 per second. Using the phonelescope technique in another experiment, but with the forefinger placed directly on the membrane of the phonelescope, Herren (**22**) did not get the high tremor rates reported above. Herren also employed this method and apparatus in a study of the effect of stuttering and of alcohol on tremor rate. The rates of normal subjects and stutterers during silence and free speech were the same, ranging between 8 and 12 per second. During stuttering and after taking alcohol the amplitude was depressed. The records taken after alcohol showed in some cases breaks in the regular rhythm which were interpreted to be new tremor rates of from 40 to 70 per second.

A second type of apparatus used by Travis (**44**) is essentially a dynamic speaker run backwards. A Formica coil is suspended by means of thin rubber strips within a field coil and an iron magnetic circuit. Changes of displacement of the Formica coil, caused by the tremor of the part of the body studied, produced electrical changes in a current activating a supersensitive Westinghouse oscillograph. The oscillograph wave was photographed on moving-picture film. The tremors were obtained from the extended fingers of the right hand, the arm being supported at the elbow. Rates of from 10 to 150 vibrations per second were observed.

An investigation of the influence of fatigue on tremor by Bousfield (**5**), in 1932, is the first study in which the actual amplitude of the recorded tremor is given. The pointer of a level which magnified the tremor in the ratio of 2 to 1 traced on revolving smoked glass. The glass plates were then projected on a screen at a magnification of 20 diameters for examination. Inspection of his obtained data reveal the fact that the average amplitude of four subjects was .025 of an inch. The average tremor rate was about 8 per second. Also the amplitude increased with the degree of fatigue as measured by the amount of work done.

Young (**49**), 1933, has conducted the most recent and most controlled study of tremor in normal adults. Records were obtained from the index finger and from the forearm. The joints other than the particular ones being studied were fixed by means of rests, plasticine casts, and paper cylinders. The articulations studied were the knuckle; knuckle and wrist; elbow and shoulder; the knuckle, wrist, elbow and shoulder. The fluctuating member under observation was coupled by means of a ball and socket to an especially sensitive diaphragm which activated a phonelescope for photographic recording. A pointer was attached to the end of the index finger and a visual fixation point was provided in the form of a target. Calibrations for the sensitiveness of the diaphragm and for magnification were not attempted. The average tremor rate was found to be around 12 d.v. a second regardless of the articulations studied, except in the case in which the

diaphragm was coupled just proximal to the wrist. The rate in this situation was 6. Tensing of the hand and fingers noticeably increased the amplitude but not the rate. Removing the visual cues slightly decreased the amplitude and the rate.

It appears from the above review of the literature that we are dealing with an extremely variable response. This response, resulting from involuntary changes in postural contraction, has two measurable aspects, rate of change and the degree of change. The former aspect has been resported to be anywhere from 5 to 500 per second, although most authorities find a vibration rate of about 10 per second. With the exception of Bousfield, a quantitative description of the second character, amplitude, has been almost totally neglected. It is important that amplitude descriptions be made in known terms so that comparisons may be drawn between various different experimental situations. A third factor which would make for the discrepancies in the descriptions of the response is that, strictly speaking, previous investigations have recorded pressure changes and not tremor oscillations. That these varying results are probably due to instrumental error is shown by the following discussion.

As we have seen, tremor was first recorded by Fernet in 1872 by means of a receiving tambour and a recording tambour. In the fifty years following, the methods employed in the recording of tremor have been essentially the same; a mechanical system, in one from or another, has been used to pick up, amplify and record the tremor. The majority of investigators have used either a receiving tambour or a recording tambour, or both; others have substituted a pivoted lever so that the tremor is picked up, amplified, and recorded by one unit.

In order that any recording system may faithfully reproduce tremor in some part of the body, it must be able to record the smallest absolute activity of the member. If it records only the larger excursions of the member and excludes smaller tremors, there will necessarily be a false reduction in the average rate and a false increase in the average amplitude. It must be noted that any recording system of a mechanical

nature will have its own inertia which may make it insensitive to small tremors. Furthermore a mechanical recording system is likely to have a vibration rate of its own, and is apt to continue in vibration after the propulsion from a tremor has ceased. These difficulties are hard to overcome for if one increases the sensitiveness of a mechanical system one at the same time increases the possibility that once set in motion, it will continue in motion because of its own inertia. We feel, therefore, that we are justified in criticizing previous investigators of tremors on two grounds. First, no experimenter has calibrated his instrument to determine the least possible movement that it is capable of recording; and second, no previously devised apparatus can be said to be wholly without lag and inertia and thus free from the distortion of the actual facts. Lack of calibration and the presence of inertia and lag will produce only a relative registration of the response. If these factors remain unknown variables, the results in different experimental situations will be incomparable and incomprehensible.

Of the modern investigators, Young, through the use of a special type of diaphragm so constructed that a slight vertical deformation gives a large air-volume displacement, has most nearly overcome the effects of lag and inertia. It is to be noted that he is the only one who stresses the variability rather than the regularity of amplitude and rate. Examination of the exhibited protocols of other experimenters reveal a remarkable uniformity of rate and amplitude. The majority of the curves are almost perfectly sinoidal.

In using the Formica coil suspended on rubber strips Travis has only a more complicated tambour and the weight of his coil probably increases its inertia. The use of a phonelescope by Travis, Young and Herren does not dispense with the possibility of lag. The use by Bousfield of a rubber band to return his lever to position and Hill's use of tambours open them to the same criticism. Hill has shown that his tambours did have vibration rates of their own.

Dispensing with a mechanical system altogether would, of course, overcome the presence of lag and inertia. One way

in which this may be accomplished is to use an optical lever system to pick up, amplify and photographically record the tremor. L. Binet (**4**) was the first to see the possibilities of an optical system and he recorded on a photographic plate the movement of a 'grain of wheat' bulb attached to the finger. He gave up this method, however, as being impractical. Beale (**2**) has recorded both the vertical and horizontal tremor in pathological cases by placing a spherical mirror on the subject's forefinger and having the subject hold it in a beam of light. The reflected light was recorded on two moving strips of bromide paper in two different planes. This apparatus was not very sensitive because of its low magnification of movement and it did not yield accurate records of either rate or amplitude. Mehrtens and Pouppirt (**33**) have described a method very similar to our own for studying pathological tremor. However, this apparatus was not calibrated for amplitude nor was the speed of the recording film well controlled. These investigators have devised methods of overcoming our main objection to previous experiments on tremor. However, as they have not standardized their procedure nor calibrated their instruments, their results are still only relatively qualitative descriptions of tremor.

We believe the above mentioned uncontrolled variables within the recording systems employed in studies of tremor and the lack of standardization of procedure are of primary importance as an explanation of the varying results obtained. The literature has shown us that if our results are to be of any consequence, we must devise a procedure which is reproducible and an apparatus which can be exactly calibrated. The lag and inertia of all parts must be reduced to a minimum. With such an apparatus we intend to make a quantitative analysis of the characteristics of normal tremor and to determine what effect, if any, mental activity has upon these characteristics. To this end we have constructed the following apparatus and have developed the following procedure.

Apparatus and Procedure

Apparatus

The idea for our apparatus was borrowed from the method used in recording the movements of the string galvanometer. Its essential feature consists of amplifying by means of an optical lever the movements of the shadow cast by placing the fluctuating member in a parallel light beam. The complete set-up is shown in Fig. 1.

The light source, *L*, is a 26-watt concentrated filament lamp (as used in the electrocardiograph machine). A ten diopter lens, *A*, projects the light in a parallel beam 3 cm. in diameter. It is necessary that this beam be composed of parallel rays so that the vertical excursions of the member interrupting the rays will be amplified in a constant

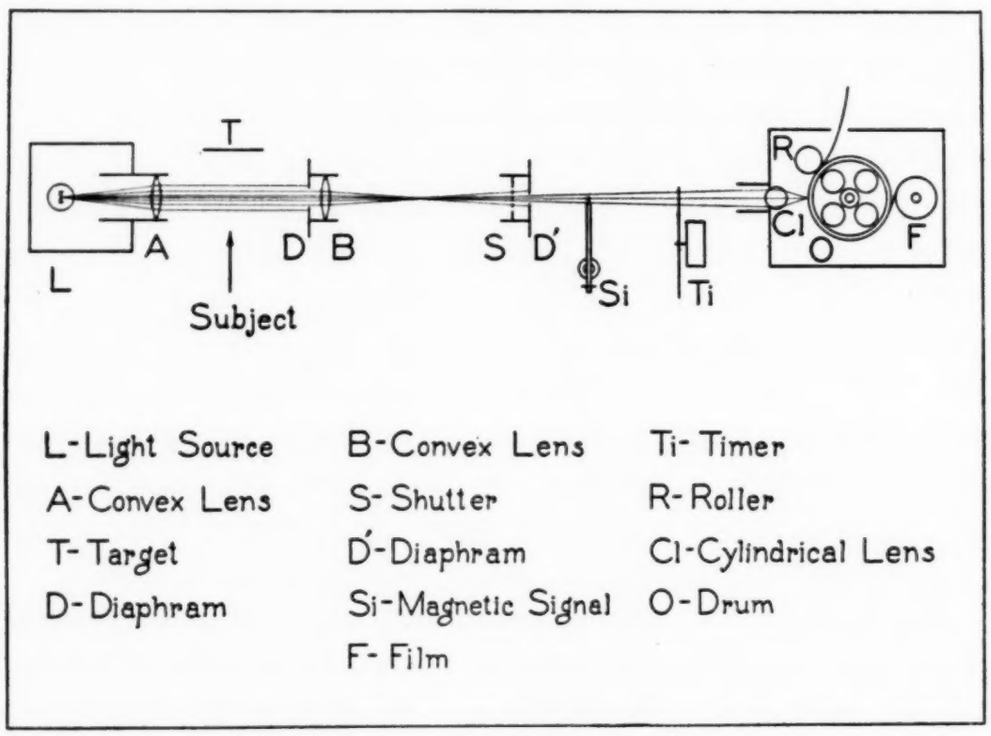

Fig. 1. Schematic diagram of the apparatus.

degree no matter whether these excursions occur in the center or in the periphery of the light beam.

On the subject's forefinger is placed a thimble to which is attached a fine wire of the type used for cleaning hypodermic needles. This wire is 2 cm. long and approximately .15 mm. in diameter. It was found that this wire as sold commercially has a recordable vibration rate when struck, so the temper was taken out by heating and then immediately cooling it. The subject holds his finger so that the wire is centered on a target and is at right angles to the light beam.

The target, *T*, is a 4 mm. hole in a thin piece of copper sheeting. The subject holds his finger so that the wire projects through the hole and is just visible to the experimenter on the other side. Excursions are thus limited to distances of 4 mm. As our film is 60 mm. and the magnification is 20 times, it will be seen that vertical excursions large enough to touch the outer edge of the target will be revealed by a departure of the shadow from the film. The target is placed at the focal distance, 10 cm., from lens *B*.

This ten diopter lens projects the shadow on to the camera, seven feet away. It amplifies the movements of the wire 20 times.

The light enters the camera through a converging cylindrical lens, *CL*, and falls as a narrow line 6 cm. by ½ mm. upon a moving film of bromide paper. The cylindrical lens was made by filling an ordinary pipette with water. The usual gradations etched on the pipette cast narrow shadows, 2 mm. apart, which are seen on the protocols (Fig. 2) as horizontal lines. The driving mechanism of the camera is a spring drive kymograph motor. A lever arrangement allowed the experimenter to start and stop the motor from a distance. The usual kymograph cylinder, connected with the driving shaft, was replaced by one 6 cm. in height to accommodate the film; 1 mm. flanges extending from the top and base of the cylinder prevented the film from slipping up or down. A small tension roller, *R*, holds the film tightly against the revolving cylinder so that it will be drawn past the light slit and out of the camera.

The timer *Ti*, is a synchronous motor driven by a 60 cycle A. C. current. The motor drives the shaft of a two vane episcotister at the rate of six revolutions per second. This timer is placed in front of the camera so that the revolving vanes will cut the light beam falling on the film. The interruptions of the beam are shown as horizontal lines in Fig. 2, the distance between each line representing an elapsed time of 1/12 of a second.

A magnetic signal marker, *Si*, is placed so that the arm of the signal extends into the light beam and casts a shadow upon the top of the film. The signal is operated by two dry cells. The circuit is completed by closing a telegraph key. This key, along with the bulb which activates shutter, *S*, and the lever for starting and stopping the camera motor, is situated behind the light source.

Calibration

Calibration of the apparatus was effected in the following manner. First, it was necessary to obtain the ratio of amplification. This was obtained by merely placing an ocular micrometer in the parallel beam of light and recording with our camera the shadows cast by the etched divisions. On the micrometer these divisions are .05 mm. apart. When recorded on the film two of these divisions equal the distance between the horizontal amplitude lines on the film. As the amplitude lines are 2 mm. apart the amplification ratio of the apparatus is 20 to 1. This ratio remains constant no matter on what part of the film the micrometer shadows fall. Thus in a recorded tremor curve, an excursion of 1 mm. on the film represents an actual tremor amplitude of only .05 mm.

The apparatus was then tested to determine the fastest possible rate of tremor that it was capable of recording. The wire from the thimble was fastened to the vibratory armature of a magnetic speaker unit. This unit was activated by a General Radio Beat Frequency Oscillator at speeds of 10, 20, 50, 100, 200, and 256 d.v. per second which were recorded in the same manner as the recording of tremor.[2] Double vibration rates up to 200 per second are easily visible, but a vibration rate of 256 per second can be seen clearly only with the aid of a reading glass. Not only does this method determine the sensitiveness of the recording system but it at the same time calibrates the timing device.

These two simple procedures give us an exact knowledge of what our apparatus is capable of measuring. It allows us to definitely state that the apparatus as so described will faithfully record tremors at least as small as .05 mm. in amplitude and which might appear at a rate as high as 200 per second.

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[2] Photographs of the micrometer and recordings of the Oscillator are included in the Dissertation deposited in the Library of the University of Virginia.

Procedure

The particular articulations under investigation are those of the second and third phalanges of the index finger of the right hand. Two healthy adults under thirty years of age served as subjects; M. S. W. (female) and R. W. (male). Both subiects were right-handed. Both were naïve as to the purpose of the experiment. The subjects were comfortably seated at the apparatus and the outstretched right arm was placed volar side downward upon a heavy wooden support. The distal part of the palm and the first phalanges rested on a block two inches high fixed to the arm support. This permitted only the second and third phalanges (the two most distal joints) to articulate and by raising the hand above the elbow level allowed the subject to "sight down" his index finger at the target.

Tremor was recorded under four conditions. In each experimental sitting tremor was recorded while the subject was doing mental subtraction and immediately before subtraction began or immediately after subtraction ceased. Each record therefore contained a period of 'mental work' and a period of 'rest.' Records were also obtained when the subject relaxed his finger as much as possible and when he voluntarily tensed his finger as much as possiole. Diagrammatically the four experimental situations are shown below.

I. Relaxed	II. Tensed

RS. Subtraction began at signal
SR. Subtraction stopped at signal

In I, the subject exerted only enough tension on his index finger to keep it centered on the target. In II, the subject was instructed to tense his index finger as much as possible. Recordings were made in situation RS (Rest-Subtraction) to determine the effect of introducing mental activity and in situation SR (Subtraction-Rest) to determine the effect of cessation of mental activity. Mental activity consisted in having the subject successively subtract '7's,' beginning with any given number from 50 to 100.

The verbal instructions given the subjects and the experimental procedure in each situation is as follows. In IRS, the instructions were, "be relaxed and keep the end of the wire centered on the target at all times. A number will be given you from which you are to successively subtract 7's. Give your answers out loud." The camera was then started and the shutter opened. After a period of approximately three seconds the arbitrary number was given to the subject and at the same time the signal key was pressed down. The subject continued his subtractions until the camera was stopped after three seconds. In ISR, the subject began mental arithmetic just before the camera was started. He was instructed, "at the command, stop! cease all mental arithmetic, make a special effort not to continue subvocally." After the subiect had made five subtractions the camera was started; the subject continued for three seconds. He was then given the command and the signal key was pressed down. Records continued to be taken for three more seconds. The subject then withdrew his arm and rested comfortably in his chair while the experimenter cut off the exposed film and labeled it. This took about five minutes. Recordings under II were then made.

The procedure and instructions in this situation were similar to that in I with the exception that the subjects were told to "tense your index finger as much as possible;

be sure that you are conscious of the proprioceptive sensations arising from your extended finger. Do not grip the hand rest with your other fingers."

This series of four situations in the order given above, IRS, ISR, IIRS, IISR, was presented to each subject on ten different days at approximately the same hour each day (4 P.M. for M. S. W., 10:30 A.M. for R. W.), thus a total of forty individual three second tremor records was obtained for each subject. The film was developed immediately after each sitting but the counting of the tremors and the measuring of the amplitude of the tremor was not begun until nearly all of the recordings had been made.

As seen from the above description of procedure, in each of the four experimental situations there is a period in which mental arithmetic has either not yet begun or has just ceased, which phase we shall designate 'rest,' and a period in which mental arithmetic is in progress, which we term 'subtraction.' In the figures and tables presented under *Results* these two periods are designated by the symbols R and S. RS indicates the situation in which the resting state preceded subtraction and SR indicates the situation in which the subjects first subtracted and then stopped at the command.

Method of Measuring

The tremors measured and counted were those occurring within a time limit of one and two-third seconds (twenty of the one-twelfth second time intervals) on each side of the appearance of the signal. In counting tremor, a tremor was defined as a change from an upward direction on the record through zero to a downward direction; *i.e.*, single displacements were counted. *A* in Fig. 2 shows this change; *B* is considered to be merely a change in the slope of one continuous curve and is, therefore, not counted as a tremor.

In treating amplitudes, however, each single vibration was measured; *i.e.*, instances of change from a downward to an upward direction were included as well as the instances of change in the reverse direction. Measurements were made of the perpendicular distance from the peak to the trough of each wave. Measurements were recorded to the nearest point .05 mm. of real distance which was represented by one-half the distance between two horizontal lines on the recording film.

Results and Discussion

Our results naturally fall under two headings. First, are presented the general characteristics of tremor; and second, the effect of mental activity upon these characteristics. As we have pointed out, the methods and apparatus used by previous experimenters makes it impossible to draw direct

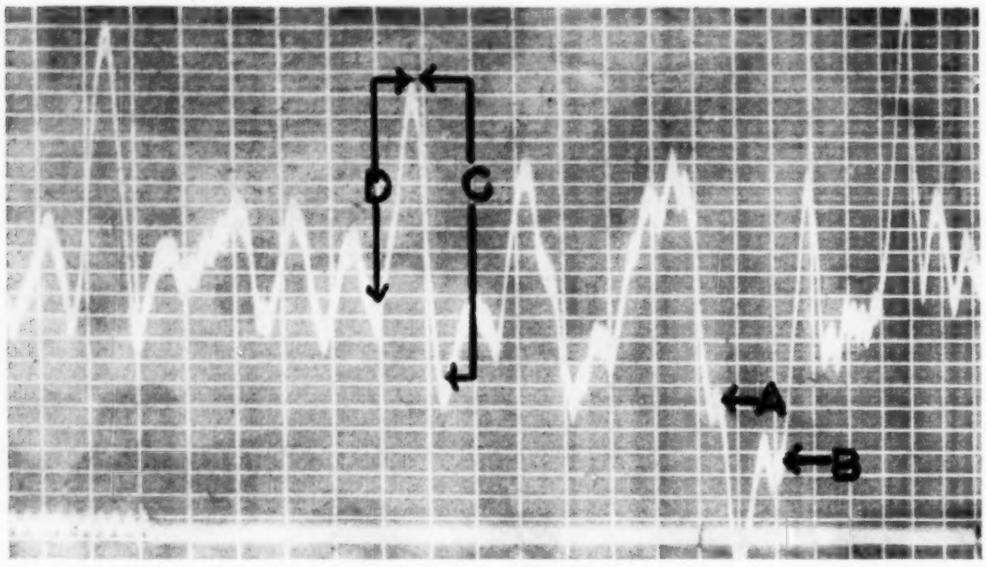

FIG. 2. A typical tremor record unreduced in size showing the method of measurement.
A. A change in direction counted as a tremor.
B. A change in slope not counted as a tremor.
C and *D*. Method of measuring two single amplitudes in one d.v.

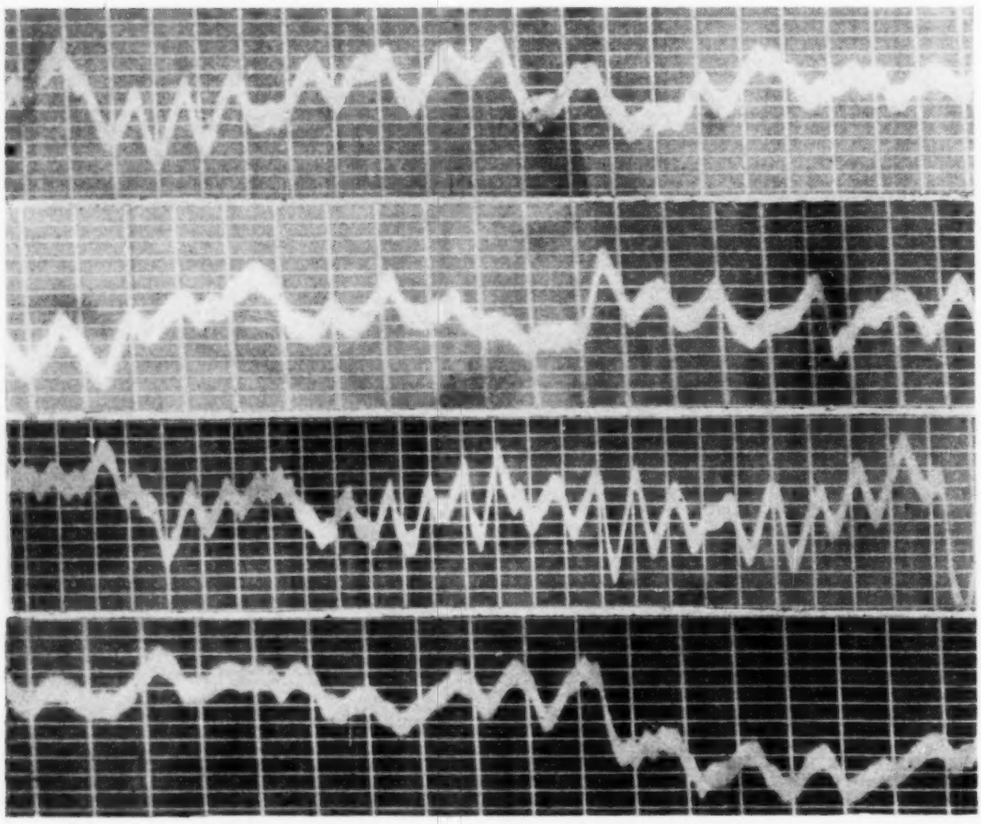

FIG. 6. Typical tremor records taken from four different subjects.

comparisons between their results and ours. We, therefore, stress the fact that the results and discussion presented below are to be interpreted only in the light of our apparatus and stimulus instructions. It is also to be remembered that tremors have been counted and measured for periods of one and two-thirds seconds and rates are presented thus in the following tables and figures, as stated previously, except that in Tables 1 and 2 results are also stated in terms of rates per second. Rates are given in d.v.'s whereas amplitudes are stated for s.v.'s.

The most noticeable characteristic of tremor that we have found is the great variability in both rate and amplitude. This variability may best be appreciated by an examination of the protocols in Figs. 2. and 6.[3] This is exemplified by the fact that in one experimental situation, lasting only three seconds, there were four tremors, each of which was only of .02 sec duration, whereas at the other extreme there was a tremor of .17 sec duration. The greatest amplitude found in an individual tremor in our records was 30 times the amplitude of the smallest observable tremor. Not only does great variability characterize individual tremors but the average rates and amplitudes for periods of one and two-thirds seconds vary greatly also. This variability in rate is expressed by the large sigmas obtained in Tables 1 and 2. In one subject the fastest tremor rate was three times the slowest rate. It is for this reason that we can speak only of a 'relatively' normal tremor rate. Tremor must be an easily modifiable phenomenon subject to changes by many physiological conditions. In our records it is impossible to predict at what point in time a tremor will occur or what its amplitude will be. This is in complete agreement with the findings of Young. Variability, however, seems to be even more extreme than he had suspected.

For the four situations—Relaxed Rest, Relaxed Subtraction, Tensed Rest, and Tensed Subtraction—the average

[3] In order to be certain that this variability was not an idiosyncrasy of our two subjects tremor recordings were obtained from twelve additional subjects, all of whom showed as great a variation in amplitude.

TABLE 1

SHOWING THE AVERAGE RATES DURING REST AND DURING SUBTRACTION IN EACH OF THE FOUR EXPERIMENTAL SITUATIONS

Subject M. S. W.

	I. Relaxed						II. Tensed					
	Situation RS		Situation SR		RS + SR		Situation RS		Situation SR		RS + SR	
	Rest	Subt.	Rest	Subt.	Rest	Subt.	Rest	Subt.	Rest	Subt.	Rest	Subt.
No. of recordings	10	10	10	10	20	20	10	10	10	10	20	20
Aver. rate per 1⅔ seconds...	25.2	21.7	24.6	23.3	25.3	22.5	22.6	21.8	22.9	20.3	22.8	21.1
Sigma distribution.....	2.7	1.6	2.3	2.2	2.5	2.1	2.6	3.7	3.1	2.9	2.8	3.5
Sigma average...	.82	.50	.71	.70	.56	.46	.87	1.2	.96	.91	.63	.78
Average rate per second.....	15.1	13.0	14.7	13.9	15.1	13.4	13.5	13.0	13.7	12.2	13.6	12.6

TABLE 2

SHOWING THE AVERAGE RATES DURING REST AND DURING SUBTRACTION IN EACH OF THE FOUR EXPERIMENTAL SITUATIONS

Subject R. W.

	I. Relaxed						II. Tensed					
	Situation RS		Situation SR		RS + SR		Situation RS		Situation SR		RS + SR	
	Rest	Subt.	Rest	Subt.	Rest	Subt.	Rest	Subt.	Rest	Subt.	Rest	Subt.
No. of recordings	10	10	10	10	20	20	10	10	10	10	20	20
Aver. rate per 1⅔ seconds...	20.1	17.9	19.9	19.5	19.9	18.7	16.6	14.8	16.6	15.5	16.6	15.1
Sigma distribution.....	3.5	3.2	3.6	3.3	3.5	3.4	2.5	1.1	2.1	2.4	2.3	1.9
Sigma average...	1.1	1.0	1.1	1.0	.79	.76	.80	.34	.66	.76	.51	.42
Average rate per second.....	12.0	10.7	11.9	11.6	11.9	11.1	9.9	8.9	9.9	9.2	9.9	9.0

tremor rates for each subject are shown in Tables 1 and 2, M.S.W.'s rates are respectively 15.1, 13.4, 13.6, and 12.6; and R.W.'s are 11.9, 11.1, 9.9, and 9.0. Our rates are in fair agreement with those (8 to 12 per second) obtained by most former investigators. In no case have we obtained rates as high as those reported by Travis (**6**).

The average rates of M. S. W. are consistently higher in all the experimental situations than those of R. W. As the

critical ratios between the two subjects are all above 3, it would appear that there are real individual differences in tremor rates.

Voluntarily tensing the finger increases the average amplitude and decreases the average rate, as shown in Tables 1 and 2 and Figs. 3 and 4. Our results confirm Eshner's original statement that there is an inverse relationship between rate and amplitude. The correlations obtained between rate and average amplitude in the individual one and two-thirds second periods were − .18 for R. W. and − .46 for M. S. W.

Inspection of the graphical representations of the distributions of amplitudes,[4] Figs. 3 and 4, show that the distributions are anything but normal. Small tremors predominate in all situations. For subject M. S. W., when the finger is relaxed 62 percent of the tremors are less than .10 mm in amplitude; when tensed, 37 percent of the tremors are less than .10 mm when relaxed, and 53 percent are less than .10 mm when tensed.

To summarize the results on the general nature of tremor, we may say that the most obvious characteristic of tremor is its irregularity in regard to both rate and amplitude. A recording of tremor which is consistently sinoidal in appearance is, therefore, probably due to instrumental error which dampens the large amplitudes and fails to pick up tremors of small amplitudes. Statistically reliable differences were obtained between the average rates on two subjects. One of the factors influencing the rate and amplitude of tremor in each subject is the degree of tension present in the member of the body studied. Tension decreases the rate and increases the amplitude. There is an inverse relationship between rate and amplitude.

We turn now to a consideration of the effects of mental work. A survey of Tables 1 and 2, already presented, shows that mental activity affects tremor in the same direction as does voluntary tension in the finger. Introducing mental

[4] Tables containing the measured amplitude of every recorded tremor are included in the Dissertation deposited in the Library of the University of Virginia.

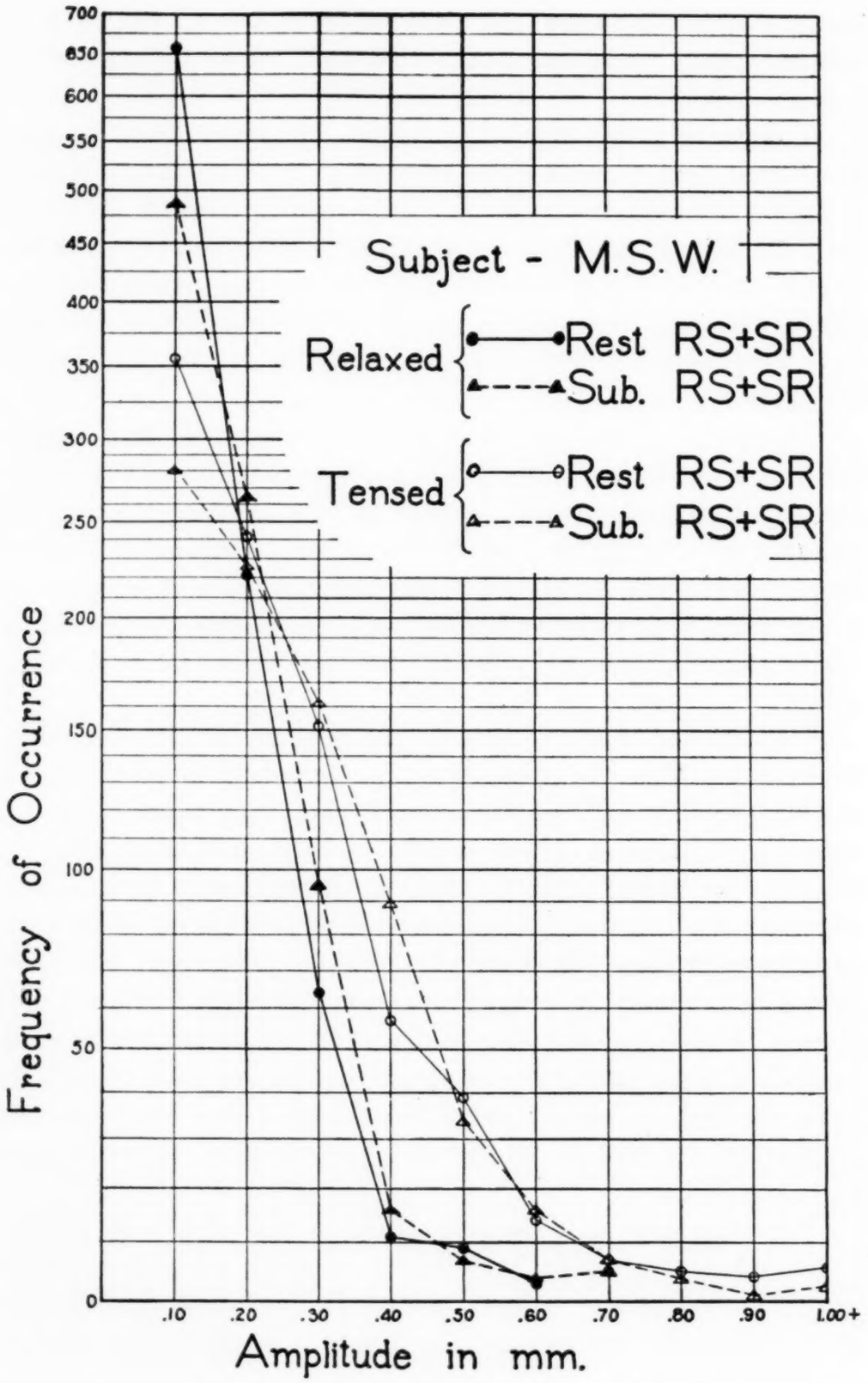

FIG. 3. Showing the number of tremors of various amplitudes recorded in the four different experimental situations. Subject M. S. W.

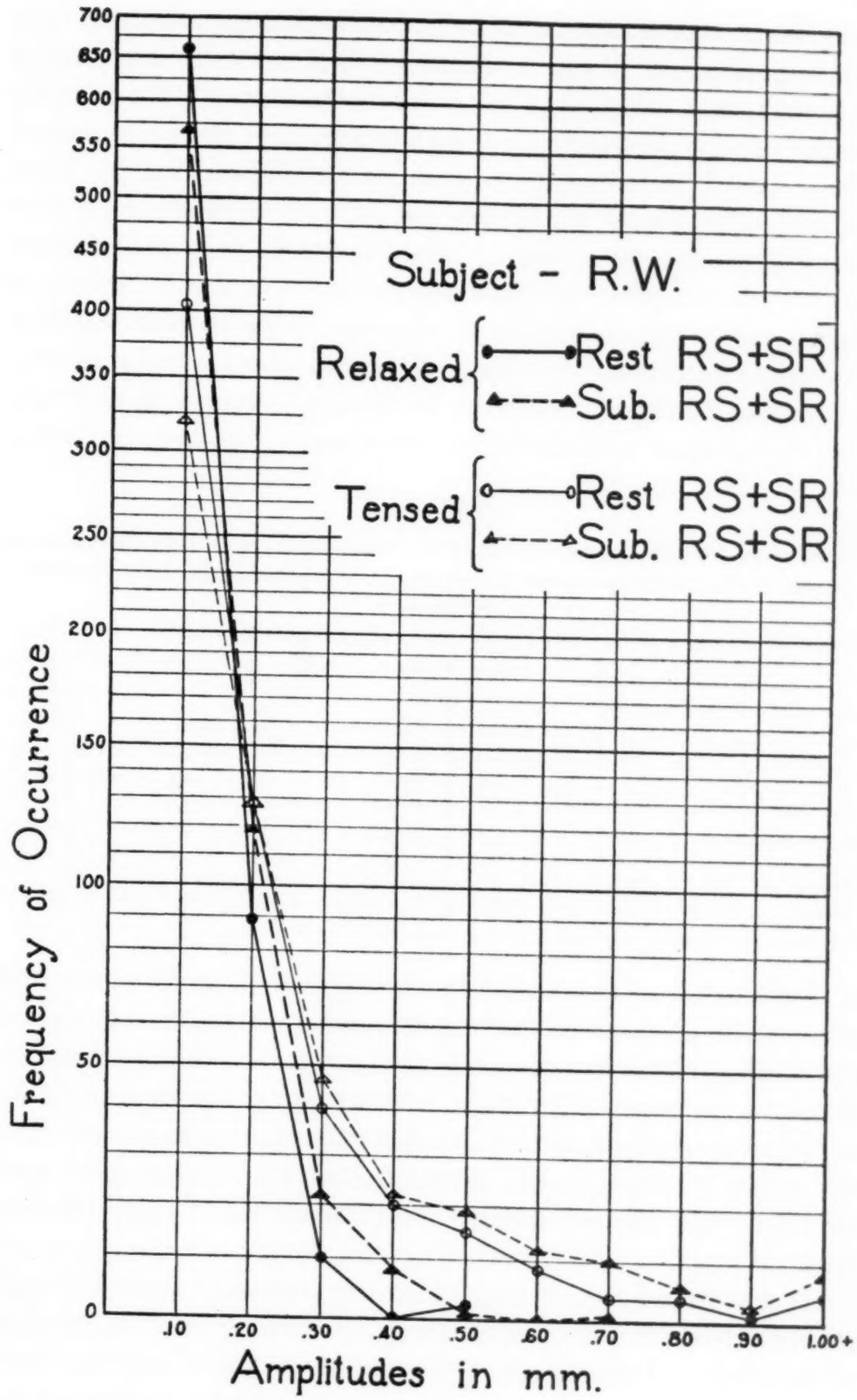

FIG. 4. Showing the number of tremors of various amplitudes recorded in the four different experimental situations. Subject R. W.

subtraction increases the amplitude and decreases the rate, the opposite effect, which occurs in "relaxation," also occurs if subtraction ceases. This is a subtle change, there being rarely any marked difference in the appearance of the record. The critical ratios of the averages in Tables 1 and 2 are presented in Table 3. These ratios, although showing that the differences in most of the situations are statistically reliable, do not give an accurate statement of the reliability of the change which occurs with the beginning or the cessation of mental activity. In using this method we are comparing the average rate of all the experimental sittings during rest with the average rate during subtraction. The daily variation

TABLE 3

SHOWING THE CRITICAL RATIOS BETWEEN THE AVERAGE RATE DURING REST AND THE AVERAGE RATE DURING SUBTRACTION IN EACH OF THE FOUR EXPERIMENTAL SITUATIONS

	Subject M. S. W.				Subject R. W.			
	I. Relaxed		II. Tensed		I. Relaxed		II. Tensed	
	RS	SR	RS	SR	RS	SR	RS	SR
Sigma difference	.96	.99	1.44	1.32	1.51	1.51	.86	1.00
C. R.	3.6	1.3	.55	1.9	1.4	.26	2.0	1.1
Chances in 100 of true diff.	100	90	71	97	92	60	98	86

of these rates, as expressed by the sigmas of the average, will necessarily produce in one experimental sitting a rate during rest that is the same or nearly the same as a subtraction rate obtained on some other day. As we are interested in determining what effect mental activity has upon the tremor at any given moment it has been necessary to compare in each protocol the rates during rest with the rates during subtraction.

It was found that the rates during rest were almost always higher than those immediately preceding or succeeding subtraction. Differences in rate were obtained by subtracting the number of tremors occurring during 'subtraction' from the number of tremors occurring during 'rest.' A

positive difference, therefore, indicates that there was a slower rate of response while doing 'mental work.' Table 4 shows the average difference in the four situations for both subjects. Figure 5 shows the distribution of the differences in rate between rest and subtraction in all four situations. When the finger is relaxed, the average rate during the resting state is 3.61 d.v. faster than when the subject is doing subtraction. There are 99 chances in 100 that this average rate will always be at least 1.69 d.v. faster during rest than during subtraction. When subtraction precedes resting the average difference in rate is not as large. The subjects reported (during the experimental sittings and before the

TABLE 4

SHOWING THE AVERAGE DIFFERENCES IN RATE OBTAINED BY SUBTRACTING THE NUMBER OF TREMORS DURING MENTAL ACTIVITY FROM THE NUMBER OF TREMORS DURING REST

Both Subjects Combined

	I. Relaxed		II. Tensed		All Situations
	RS	SR	RS	SR	RS + SR
Number	20	20	20	20	80
Average difference	3.61	1.25	1.80	2.40	2.21
Sigma distribution	2.9	2.4	2.8	2.2	2.6
Sigma average	.64	.53	.62	.50	.29
Average −3 sigma average	1.69	−.34	−.06	−.90	1.34

data were compiled) that it was practically impossible to cease subtraction immediately at the command. Since subtraction is, therefore, going on in these particular situations during the period designated as 'rest,' this probably accounts for the decrease in the average differences. It can also be seen that the average difference in rate is smaller when the finger is tensed. If the effect of mental activity is to increase the tension in the particular muscular system under investigation, the greater the original tension of the system, the smaller the relative effect of mental activity should be.

The effect of subtraction on the amplitude on tremor is to decrease the number of tremors of small amplitude and to correspondingly increase the number of tremors of large

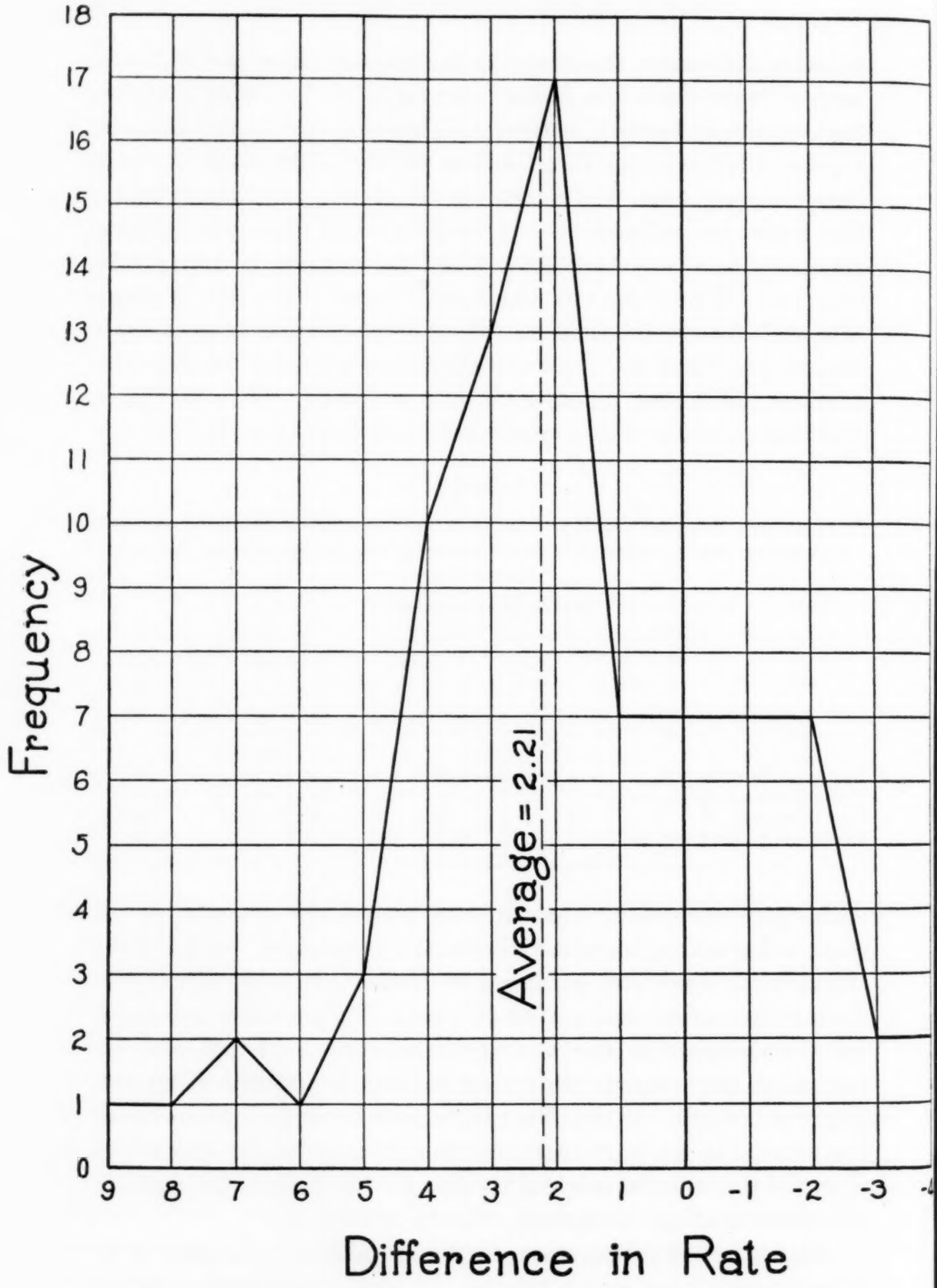

FIG. 5. Showing the distribution of the differences in rate obtained by subtracting the number of tremors occurring during mental work from the number of tremors occurring during rest in each individual recording.

amplitude, as shown by Figs. 3 and 4. Again it is to be noticed that this effect is lessened when subtraction precedes rest and when the finger is tensed. Figs. 3 and 4 show that there is a progressive decrease in the number of smaller tremors from the situation in which the finger is relaxed and there is no mental activity to the situation in which the finger is tensed and subtraction is in progress. As the number of small tremors decrease tremors of larger amplitude appear.

It would seem, therefore, that we have a delicate method of measuring involuntary changes in neuro-muscular activity. These changes are apparently intimately related to changes in degree of psychical activity present in the individual. A change in muscular tonicity is revealed by an increase of amplitude and a decrease in rate of the involuntary oscillations of the forefinger.

Interpretative Discussion

Normal tremor has usually been thought of as being the manifestation of spontaneous rhythmical activity in some nerve center; and abnormal tremor as due to removal by disease or lesion of the inhibitory control of the higher over the lower centers, or due to some irritative discharge from the cortex. The most common view has been that in tremor the higher centers of the brain act directly upon the musculature, producing oscillations in the extremities which synchronize with waves of nerve impulses. This view has persisted primarily because tremor has been generally regarded as a 'clinical sign' denoting abnormal change in brain functioning. Etiological research has, therefore, been mostly interested in determining the location and effects of pathological conditions in the brain. The fact that tremor may be present in any continuous muscular response, no matter how simple the reflex arc may be, has not been emphasized. Investigators who have shown that tremor is present in normal healthy individuals have either accepted the clinical concepts or have neglected to offer any interpretation of tremor. We wish to show that on such modern physiological evidence as that summarized by Fulton (**19**) and by Creed, Denny-Brown

et al (9), tremor may be explained as being an inevitable phenomenon of postural contraction, inherent in the simplest reflex arc and not dependent upon the higher centers for its origin and not synchronizing with discharges from the higher centers. We hope to be able to show that tremor must occur in any postural contraction.

Sherrington has defined posture as "those reactions in which the configuration of the body and its parts is, in spite of forces tending to disturb them, preserved by the activity of contractile tissue." We have measured the involuntary postural changes of the index finger. Although we have used the expression, 'relaxed,' to describe one particular situation, it has been used only in a relative sense; it is obvious that in maintaining posture the finger is in no sense ever relaxed. By the use of the term we have wished merely to indicate that the subject was exerting less voluntary tension on the finger than in the situation described as 'tensed.' When our subjects attempted to maintain the position of the finger, exerting the least possible effort, it was found that there were rapid and minute postural fluctuations. The rate of fluctuation and the degree of fluctuation were extremely varied. Voluntarily tensing the finger, or increasing mental activity, caused these fluctuations to become larger in amplitude with a corresponding decrease in the rate of oscillation. Any adequate explanation of these phenomena must be made in terms of the known facts concerning the 'activity of contractile tissue.'

Adrian and Bronk (1) have shown that voluntary muscular contraction in man is maintained by a series of nerve impulses which range from 5 to 50 or more per second in each nerve fiber. No muscle cell contracts continuously. The muscle as a whole maintains continuous contraction only because as fibers relax other fibers are set into action. When tension is increased, the frequency of impulses rises, and more and more muscle fibers come into play.

Action currents from muscle groups are asynchronous (1). Asynchronism increases with the number of fibers responding. The picture is further complicated by introducing the an-

tagonistic effects of the flexors digitori sublimis and profundus. The two groups, relaxing and contracting irregularly, as shown by Golla and Hettwer (**21**) produce an extremely irregular antagonistic effect. We, therefore, have in these facts an adequate neurological explanation for the presence of tremor and for the observed variability of tremor amplitude and rate. It is impossible to avoid tremor, and tremor is essentially irregular.

How is the increase in tremor amplitude under conditions of tension explained by the concepts here employed? The answer is that tension increases the number of motor units responding, thus increasing the pull upon the finger and causing it to undergo wider excursions.

However, Adrian and Bronk have shown that the *rate* of response of individual muscle fibers increases with tension. It is, therefore, necessary to explain why a slow rate of tremor occurs under conditions of tension. It is certain that because of the fact that the articulation of the phalangeal joint is mechanical in nature some of the smaller oscillations will necessarily be dampened out at all times, but more of them will be damped out when friction in the joint is increased by strong tension of the muscles. A further explanation is found in the fact that increasing the frequency of contraction in each fiber will also increase the possibility of more and more fibers responding simultaneously. Even if the number of fibers involved remained constant the greater frequency of discharge would in itself increase the strength of the response. By increasing the amplitude of the muscular response, the individual fiber discharges will be masked. Thus, although the frequency of response in the individual fiber as shown by electrical potential change is increased, the observed response of the entire muscle bundle becomes slower as the extent of the reaction becomes larger. We can conclude, therefore, that the observed tremor is due to a continuous discharge of nerve impulses to the muscle groups and that an average increase in the amplitude of the oscillations may be interpreted as indicating an increase in the rate of nerve impulses reaching the muscle. In voluntary tension this increase of rate of

afferent discharge has its origin in the cerebrum. We believe that in explaining the increase of nerve impulse discharge during voluntary tension we may arrive at an adqeuate explanation of why tension occurs during mental activity. That mental work has a muscular effect similar to that of voluntary tension has been shown by our results, and by the studies of Tuttle (**46**), Jacobson (**25**) (**26**), Freeman (**16**) and others.

A clue to the explanation of this fact is derived from the experiments on the "crossed extensor reflex" (**32**). These experiments have demonstrated that after excitation of the crossed reflex the stretch reflex is more easily elicited. This is believed to be due to the recruitment characteristic of the motor neurons involved in the stretch reflex. That is, if successive stimuli are applied at a constant rate the intensity of the stretch reflex will increase because the excitability of the motor neurons will be raised and more motor units brought into action. The crossed reflex apparently raises the excitability of the stretch reflex. "This analysis of the blending of the reflexes is important for the light which it sheds on volitional movement. The stream of impulses descending the pyramidal tract may be regarded as analagous to the volleys in the afferent fibers of a crossed extensor reflex" (**9**). If this be true of volitional movements, it is possible that mental activity may have the same effect. Afferent impulses set up by cerebration blend with the motor neurons already in activity in maintaining the postural reflex.

Of the neurons of the moto-neurone pool responsible for maintaining the activity, some are just subliminal at any moment and an additional discharge from the cortex will raise them to liminal value thus causing them to increase the efferent impulses to the muscle. The cortex is not to be thought of as discharging efferent impulses directly into the responsive system. The effect of efferent discharges from the cortex is to facilitate the activity already in progress. All that is necessary for this phenomenon to take place is that there be a reflex center which is activated by stimuli and which is in connection with the cortex either directly or indirectly. Fulton (**19**)

has beautifully diagramed how this dynamic interaction may be theoretically possible.

As to where this facilitation effect during mental work takes place, we can only make a hazardous guess. It would involve going into all of the ramifications of the central nervous system. In a comprehensive review of the control of tonus, Langworthy (**29**) has come to the conclusion that "only at the level of the vestibular and red nuclei is there evidence of influences tending to augment or inhibit tonus as a whole." The red nucleus is one of the most important internuncial junctions, receiving impulses from the cerebellum, cortex and corpus striatum. As early as 1904 Gordon Holmes (**24**) had stated that tremor was due to disturbance of the functional equilibrium of the cerebellum and cerebrum secondary to a lesion of the cerebello-rubral system. Whether the red nucleus or some other portion of the midbrain is the integrating center does not materially affect our assumptions.

In positing the above assumptions we realize that they are contrary to the conventional view that the main function of the cerebrum is to inhibit the activity of the phylogenetically older reflex paths. That the cortex does exercise this function cannot be questioned in the light of modern experimental knowledge. We do believe, however, that in stressing the inhibitory function, the excitatory nature of the cerebral cortex which is no less important (**19**) has been shoved into the background. In contrast to the accepted theory that tremor is to be accounted for by the release of cortical influence over a simpler mechanism, or due to the rhythmic discharge from a 'tremor center,' we wish to emphasize that tremor is a phenomenon which is encountered in any active contractile tissue. Also there is a firm physiological basis (cited above) for explaining increased activity in the muscular system as being due to an addition of nervous energy from the higher centers as opposed to the view that it is due to a withdrawal of inhibitory activity.

The above theoretical discussion necessitates conceiving the neuromuscular system as a functional entity. Any response may be said to be the result of the interaction of all

the activities occurring within the system. The character of the responses which will take place upon stimulation is dependent upon the degree and nature of the activity present within the integrated organism at the moment of stimulation. The interrelations and interaction of function makes for a dynamic system in that activity implies not only a present change in state, but also a future change in function. For that reason there can be no constancy or perfect predictability of the effect of any specific stimulus. This makes the conception of a center which would initiate and control tremor untenable. To be sure, there are afferent and efferent pathways and cerebral areas which are functionally of different importance and functionally discrete, in that, by their removal certain differential characteristic behavior occurs. There is, however, no justifiable reason to ascribe to a localized area an operational independence based upon a description of behavior occurring after its destruction.

Interpreting the results of previous investigators in the light of this concept of unity of action, it is to be expected that muscular responses would be observed during 'psychical activity.' That these responses are in the nature of tension and increased muscular activity is explained by our discussion. As these changes may be very minute and subtle they are not observed more often because of the methods used to detect them.

Our results have a direct bearing upon the theoretical relationship between voluntary movement and the rhythmical activity of muscle as recently advanced by Travis (**45**). He has stated that in the majority of cases 'willed' movement blends with and does not interrupt rhythmic tremor. Thus a voluntary reaction must wait upon the tremor phase as it cannot be initiated until the direction of the tremor is in the same phase required by the voluntary action. In order to observe, as Travis has, that voluntary action synchronizes with the tremor, the individual tremor must be predictable on the basis of the record which has just preceded the signal for voluntary action. Otherwise one would not be able to tell whether the voluntary action was a continuation of, or an interruption of, tremor. We have shown that the most noticeable characteristic of tremor is its irregularity in regard

to both rate and amplitude. Because of this irregularity it is impossible to predict when a change in the direction of tremor will occur. It is, therefore, impossible to observe the effect of voluntary action upon an individual tremor.

In attempting to explain the fact that a tapping rate faster than 12 per second has never been observed because the involuntary rhythm is never higher than 12 per second, Travis completely ignores his previous findings of an involuntary rhythm of 300 to 600 per second (**42**) (**43**)! A more logical explanation of the upper limit of voluntary rhythmical activity is based upon our findings of an inverse relationship between rate and amplitude. In a voluntary activity the amplitude is increased thus reducing the rate of the response; if one could voluntarily control the amplitude of the response in tapping so that it would not exceed, say .10 mm., there is no reason to suppose that tapping rates higher than 12 per second could not be obtained.

Our results and theoretical discussion offer a new interpretation of some of the facts regarding pathological tremor. Abnormality is in reality only a matter of degree. Pathological tremor is abnormal because the amplitude has been increased to such a degree that tremor is obvious. Due, however, to the inverse relationship between rate and amplitude, pathological tremor cannot be merely thought of as an exaggeration of a normal phenomenon. An exaggeration of amplitude means that there must be a decrease in rate. Abnormal tremor being a change in degree it appears that a more thorough analysis of the characteristics of the normal phenomenon and the factors affecting these characteristics would lead to a better understanding of the causation of tremor in pathological conditions. In this regard it is also necessary that the concept of functional unity of neuromuscular system again be stressed. Pathological tremor can be produced by a variety of causes because tremor is due to the action of a system which can be influenced at any point.

Summary

1. An apparatus is described which makes possible probably for the first time an exact quantitative analysis of the rate

and amplitude of the involuntary oscillation during postural contraction.

2. It was found that when the right index finger of a normal human adult was extended the most noticeable characteristic of tremor is its irregularity in both rate and amplitude. The rates obtained were in general agreement with those reported by the majority of investigators (5 to 15 per second) but no rates were ever observed as high as those reported by Travis (50 to 600 per second). Amplitudes vary between .05 and 1.5 mm, over 50 percent of the tremors being under .10 mm in amplitude. There is an inverse relationship between rate and amplitude, apparently because large vibrations mask the effect of individual muscle fiber contractions, thus reducing the number of small tremors in the record.

3. Voluntary tensing the finger increased the amplitude and decreased the rate of the tremor. The effect of mental work is to produce a measurable change in the same direction as that caused by voluntarily tensing the finger.

4. In the light of the known physiological facts regarding the activity of contractile tissue tremor is an inevitable phenomenon of postural contraction, inherent in the simplest reflex arc and not dependent upon the higher centers for its origin. It is influenced, however, by the activity of the higher centers. The apparent effect of mental activity is to increase the number of excitatory nerve impulses descending from the cortex to the centers which maintain postural contraction, with the result that there is an increase in amplitude and a decrease in frequency of tremor.

5. An explanation of tremor, whether normal or abnormal, observed in an intact organism must be made in terms of the functional unity of the neuro-muscular system.

(Manuscript received July 9, 1937)

References

1. Adrian, E. D., and Bronk, D. W., Frequency of discharge in reflex and voluntary contractions, *J. Physiol.*, 1929, **67**, 119, 151.
2. Beale, C. G., New method of recording tremors, *Arch. Neurol. Psychiat.*, 1925, **14**, 751–757.
3. Binet, L. R., Le travail et le tremblement, *Rev. gen. Sci. pur. appl.*, 1918, **29**, 214–217.

4. ——, Étude technique du tremblement. *Pr. med.*, 1919, **27**, 561.
5. Bousfield, W. A., The influence of fatigue on tremor, *J. Exper. Psychol.*, 1932, **15**, 104–107.
6. Breillot, *Des tremblements; etude de semiologie et de clinque.* Paris, 1885.
7. Busquet, H., *Le tremblement physiologique.* Paris, 1904.
8. Charcot, J. M., Leçons sur les Maladies du Systeme nerveaux. Paris, 1887, t. 3, 272.
9. Creed, R. S., Denny-Brown, D., Eccles, J. C. Liddell, E. G. T., and Sherrington, C. S., *Reflex activity of the spinal cord.* Oxford, Clarendon Press, 1932.
10. Dana, C. L., The clinical characters and diagnostic significance of tremor, *Med. News*, 1892, **61**, 673–675.
11. Debove, M. and Boudet de Paris, Recherches sur la pathogenie des tremblements, *Arch. neurol.*, 1880, **1**, 191–212.
12. Dutil, A., *Étude clinque des tremblements hysterique.* Paris, 1891.
13. Eshner, A., A graphic study of tremor, *J. Exper. Med.*, 1897, **2**, 301–312.
14. Ferand, A., Physiologie pathologique du tremblement, *Union med.*, 1868, 3. s., **5**, 789, **6**, 359.
15. Fernet, C., *Des tremblements*, Paris, 1872.
16. Freeman, G. L., Mental activity and the muscular processes, *Psychol. Rev.*, 1931, **38**, 428–449.
17. ——, Changes of tonus during completed and interrupted mental work, *J. Gen. Psychol.*, 1930, **4**, 309–334.
18. Fubini, S., Nuovo Metodo per scrivere il tremore, *Ann. univ. di med. e chir*, 1886, **276**, 391–399.
19. Fulton, J. F., *Muscular contraction and reflex control of movement.* Baltimore: Williams and Wilkins, 1926.
20. Gougelet, A., *Du Tremblement.* Paris, 1883.
21. Golla, F. L., and Hettwer, J., A study of electromyograms of voluntary movement, *Brain*, 1924, **47**, 57–69.
22. Herren, R. Y., The relation of stuttering and alcohol to certain tremor rates, *J. Exper. Psychol.*, 1932, **15**, 87–96.
23. Hill, A. V., The tetanic nature of the voluntary contraction in man, *J. Physiol.*, 1921, **55**, 14–16.
24. Holmes, G., On certain tremors in organic cerebral lesions, *Brain*, 1904, **27**, 327–375.
25. Jacobsen, E., Differential relaxation during reading, writing, and other activities as tested by the knee jerk, *Amer. J. Physiol.*, 1928, **86**, 675–693.
26. ——, Electrical measurements of neuromuscular states during mental activities, *Amer. J. Physiol.*, 1930, **91**, 567–609. Also **94**, 22–34.
27. Jaubert, L., *Essai sur le tremblement.* Paris, 1880.
28. Lamacq, L., Semeiologie des tremblements, *Arch. neurol.*, 1896, 2. s., **2**, 226–228.
29. Langworthy, O. R., The control of tonus after injuries to the brain or spinal cord of man, *Medicin*, 1932, **11**, 225–262.
30. Le Filliatre, G., Nouvelle methode graphique permettant d'enregister tous les tremblement, *Arch. neurol.*, 1894, **28**, 161–167.
31. ——, *Nouvelle methode graphique permettant d'enrigester tous les tremblement. Application de cette methode dans un essai sur les troubles moteurs de l'alcoolisme.* Paris, 1895.
32. Liddell, E. G. T., and Sherrington, C. S., Reflexes in response to stretch (myotatic reflexes), *Proc. Roy. Soc.*, 1924, **96B**, 212–242.

33. Mehrtens, H. G., and Pouppirt, P. S., Recording of tremor, new method, with some account of its clinical significance, *Calif. and West. Med.*, 1928, **29**, 184–186.
34. Meyer, E., and Parisot, P., Etude graphique sur le tremblement senile, *Cong. Franc. de med.*, 1896–7, **3**, fasc. 2, 386.
35. Peterson, F., A contribution to the study of muscular tremor, *J. Nerv. and Ment. Dis.*, 1889, **16**, 99–112.
36. ——, Notes upon some kymographic tracings of tremor, *New York Med. J.*, 1894, **59**, 294–297.
37. Plateau, A. G., *Sur le tremblement.* Paris, 1867.
38. Saint-Mezard, E., *Etude clinque sur le tremblement.* Bordeaux, 1883.
39. Selice, H., *Études sur le tremblement.* Paris, 1876.
40. Schäfer, E. A., On the rhythm of muscular response to volitional impulses in man, *J. Physiol.*, 1886, **7**, 111–117.
41. Sherrington, C. S., Decerebrate rigidity and reflex coördination of movements, *J. Physiol.*, 1898, **22**, 319–332.
42. Travis, L. E., and Dorsey, J. M., Some high tremor frequencies, *Proc. Soc. Exper. Biol.*, 1931, **29**, 330–332.
43. Travis, L. E., and Hunter, T. A., Muscular rhythms and action currents, *Amer. J. Physiol.*, 1927, **81**, 355–359.
44. Travis, L. E., and Hunter, T. A., Tremor frequencies, *J. Gen. Psychol.*, 1931, **5**, 255–261.
45. Travis, L. E., The relation of voluntary movement to tremors, *J. Exper. Psychol.*, 1929, **12**, 515–524.
46. Tuttle, W. W., The effect of attention or mental activity on the patellar tendon reflex, *J. Exper. Psychol.*, 1924, **7**, 401–419.
47. Wechsler, I. S., A Text-Book of Clinical Neurology. Philadelphia: W. B. Saunders Co., 1930, 725 pp.
48. Wolfenden, R. N., and Williams, D., A note on the rhythm and character of certain tremors, *Brit. Med. J.*, 1888, Part 1, 1049–1050.
49. Young, I. C., A study of tremor in normal subjects, *J. Exper. Psychol.*, 1933, **16**, 644–656.

MUSCLE POTENTIALS AND CONDITIONING IN THE RAT[1]

BY WALTER S. HUNTER

Brown University

In a previous paper Prosser and Hunter (**2**) described experiments in which unconditioned reflexes of the rat were extinguished and disinhibited. The work was done on startle responses to sound in the normal animal and on tail reflexes to contact in the chronic spinal animal. When stimuli just supra-liminal for the response in question were repeated at intervals of 10 to 15 seconds, the response weakened and finally disappeared, after which it could be disinhibited. Records of muscle potentials were secured with concentric needle electrodes and suitable amplifying and recording systems. The results, which were analyzable in terms of individual motor units, indicated that with extinction there was 'a gradual diminution in the number of active motor units, a decrease in the duration of the after-discharge, but no change in latency for any units' (p. 617). In some cases with normal animals auditory stimuli just too weak to elicit the startle response were used and paired with an electric shock. This paired 'conditioning' procedure was sufficient after some trials to increase excitability to the point where the reflex response was elicited by the previously ineffective stimulus. The action potential picture of the extinction of this response was the same as that for the startle response to a more intense stimulation. On the basis of various controls the authors concluded that in the spinal rat extinction and disinhibition were processes occurring in the internuncial neurones.

Inasmuch as in the experiment described above 'conditioning' seemed clearly to be only a matter of raising the

[1] This experiment was supported by a grant from the American Association for the Advancement of Science. I wish to thank Dr. E. H. Kemp for aid with the apparatus in the early stages of the work.

excitability of the centers controlling the leg response rather than the making of new functional connections in the centers, since the 'conditioned' startle had the same latency as the unconditioned response, the authors doubted that true conditioning had occurred. In the present experiment I have sought to gather information on the activity of individual motor units, and hence on individual motor neurones, during the process of conditioning and extinguishing a leg response to light stimulation. The general method was as follows: An untrained adult rat was rendered generally immobile by winding it with 2-inch bandaging and adhesive tape, leaving only the rear legs, the head and tail protruding. The animal was then tied on a holder through which the legs projected to be fastened by slightly tensed rubber bands to a rod beneath them. Fine wires from an inductorium were wound above the rat's left hind foot as a shocking device. Concentric needle electrodes were then thrust into the gastrocnemius muscle of the same leg and were held firmly in place by adhesive tape. Under these conditions, little if any ankle or knee flexion was possible, so that the recording approximated isometric conditions. The rat was now placed in an electrically shielded, semi-sound-proof box whose door contained a double glass window toward which the rat's head was pointed.

Muscle potentials were recorded with a Clough-Brengle cathode-ray oscillograph, amplifiers and a loud speaker. Photography was with a 16 mm Filmo camera. The only illumination in the experimental room came from the oscillograph tube and from small apertures specially placed in the box containing the stimulus light. The result was that the rats were partially dark-adapted during the experiments. The subjects were allowed to rest for an hour in the dark after first being placed in the apparatus. They were then given one unreinforced light stimulus to determine the initial effect of the light on the motor units concerned. Paired stimulations of light and shock were now given at the rate of two per minute for 15 minutes. This was followed by a 30-minute rest in darkness, after which came 30 more paired

stimulations. After a conditioned response to the light had been so well established that it appeared on some 3 successive unreinforced stimulations, extinction trials were begun. These continued at 30-second intervals until the loud speaker or the pattern of response seen on the cathode tube face when the oscillograph was set on linear sweep indicated that the light produced no response. At this point an effort was made to disinhibit the extinguished response by opening the door of the box and generally disturbing the animal, usually by pinching. Photographs were made with the initial light stimulus and with other unreinforced light stimuli after each successive 30 paired stimulations. As conditioning or extinction progressed more frequent photographs were often taken.

The intensity of the stimulating light at the eye of the rat was approximately 0.7 foot candles as determined with a Macbeth Illuminometer. The light stimulus, which was noiselessly presented, lasted for about one second. The shock, when given, began about one-half second after the light was exposed and terminated with the light or just after it.

Startle Responses.—The results both from the films and from the loud speaker indicate that startle responses of the gastrocnemius units are rarely present as a result of visual stimulation under the present conditions. (This is true even where a photo-flood light is used as described below.) Record 1 of Fig. 2 is the only case where short latency responses have been secured with the initial stimulation. Here a single unit is fired twice by the light, first with a latency of 50 ms and again 185 ms later. In record 5 of this figure there may be a response at a latency of 40 ms. Record 6, Fig. 1, shows a single unit at 35 ms; and record 10 of the same figure has a spontaneously firing unit which speeds up after a latency of 100 ms.

Closely related to startle reflexes would be the reflex tensing of the fibers of the gastrocnemius, a change in tension which would be reflected in the oscillograph record as a change in the frequency of the potentials. Prior to conditioning in any one experimental series, the records show that

with no animal was there a change in the frequency of firing of spontaneous units as a result of the light. (An examination of Prosser and Hunter's original records reveals no case where the rate of firing of spontaneous units was affected by the auditory stimulus used.) Special efforts were made to check this point in the following way. An untrained rat was used with the electrodes so placed that they recorded a motor unit firing at a slow and regular frequency as determined by the loud speaker and by the image of the linear sweep on the tube face. When the experimental light was flashed in the rat's semi-dark-adapted eye, no change in frequency could be detected. A mazda 105–120 volt photo-flood lamp was then placed 12 ins from the rat's eyes. When this lamp was turned on there was still no change in the frequency of the units. I know of no theoretical reason why light stimulation of high intensity should not have a reflex effect on such muscle tensions, but no such effects occurred in the present experiments.

The short latency responses above described may be termed startle responses and they are probably mediated via the colliculus and not via cortical centers. Bartley (1) has shown with the rabbit that the latent time of a cortical response to continued light stimulation of approximately 1200 foot candles (calculated from his 400 c/ft^2) is about 40.5 ms. Since the latency varies inversely with light intensity, the latency of cortical response to a light intensity as low as 0.7 foot candles, granted that it could be measured, would be very much greater than 40 ms. (Bartley reports difficulty in detecting cortical potentials to light of 150 c/ft^2, although occasional responses occurred to 20 c/ft.^{2})

Conditioning.—As previous work has indicated, rats differ greatly in the speed with which they can be conditioned. In the present study occasional conditioned responses have occurred on the first day's training after 90 paired stimulations of light and shock. Well established responses have usually required some 200 stimulations, and have involved at least two experimental days. After this, however, it has been possible to condition and extinguish the response at

least once on a given day. Observation of the rat through the window of the experimental box indicated that head and 'squeal' responses are at times conditioned to the light prior to any conditioned response in the gastrocnemius muscle.

Figure 1 shows a record of conditioning and extinction with a rat that had been put through conditioning training on two previous occasions only one of which was partially successful. In record 1, taken before conditioning in the present series, there is no response to the light although a spontaneous burst of potentials was under way as the light stimulus started. It is further to be noted that the regularly firing spontaneous unit is unaffected in rate by the light. Record 3 was made after 90 conditioning trials. There is a definite conditioned response involving some 8–10 spikes which begins with a latency of 240 ms and lasts for 135 ms. Also to be noted is the marked activity of distant units indicated by the shift and irregularity of the base line. Record 4, taken one-half minute later and without intervening reinforcement, shows two bursts of three units each beginning with a latency of 410 ms and the total lasting 50 ms. In addition a single unit fires once after the second of the above bursts. In record 6 the conditioned response has been reduced to one or two units the first of which has a latency of 290 ms. There is still a slight shift of the base line. Records 3–6 inclusive were made without reinforcement, and the process of extinction revealed involves a reduction in the number of active units with an increase in latency.

A more complete picture of the changes in latency with conditioning and extinction can be given as follows. The rat of Fig. 1 gave its first conditioned responses after 120 trials with latencies of 520 and 630 ms respectively. One hundred and fifty stimulations later, the latencies were reduced to 300 and 330 ms. When tested 10 days later no response was made to the light until after 90 re-conditioning trials. The latency here was 240 ms. During extinction the latencies of 3 photographed responses were respectively 410, 290 and 480 ms. This tendency to reduce latencies with conditioning and to increase them during extinction is sup-

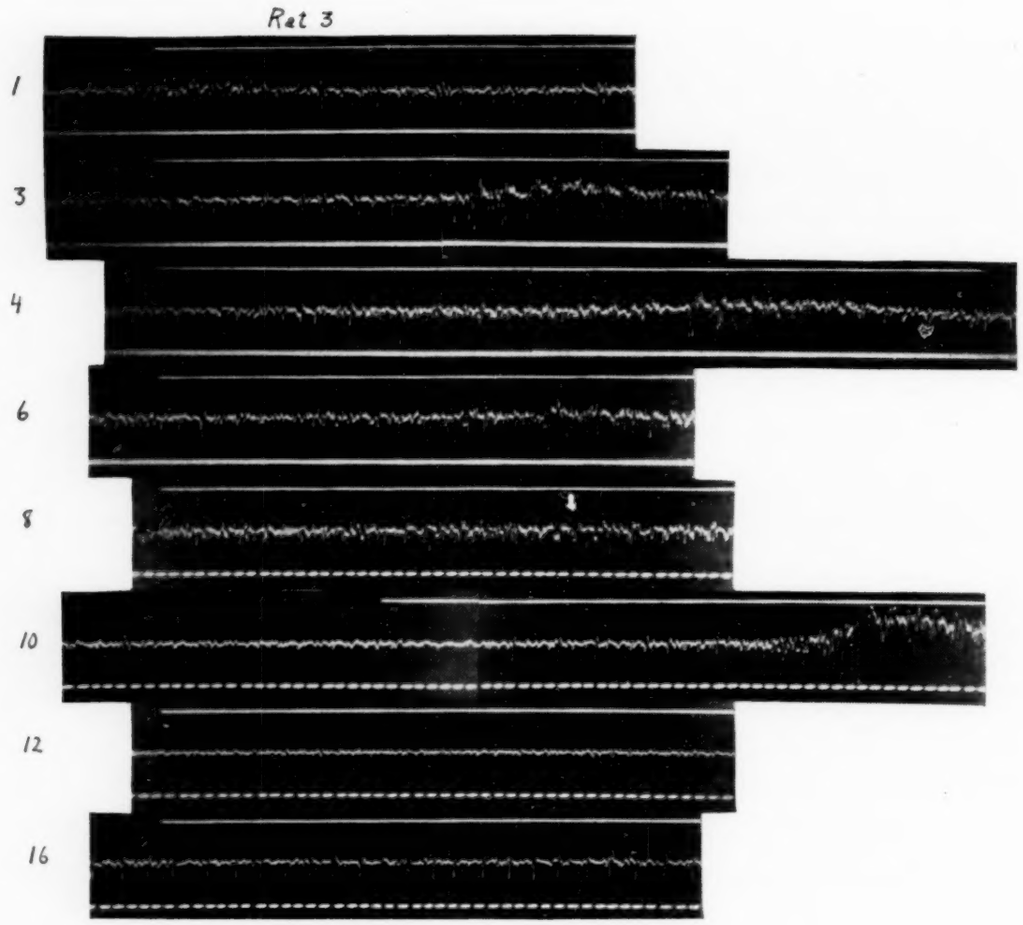

FIG. 1. Conditioning and extinction

1, before conditioning; 3, after 90 conditioning trials; 4, 0.5 min. interval after 3; 6, 1 min. after 4; (3, 4, and 6 were therefore the beginning of extinction as well as the end of conditioning); 8, after 4 more extinction trials; 10, after 30 re-conditioning trials; 12, after 14 extinction trials; 16, after 11 more extinction trials including an attempted disinhibition.

Upper line, light stimulus; lower line, time in 10 ms. (Film speed same in all records.) Read from left to right.

ported by other records of the present experiment and by the results of other investigators. It is to be contrasted with the results secured by Prosser and Hunter on the 'conditioning' and extinction of startle and spinal reflexes where no changes in latencies were found.

Between records 6 and 8 the rat rested in the dark for 30 minutes. Record 8 shows a further reduction of the conditioned response. One unit is present at a latency of 350 ms, but there is no change in the background to reveal the activity of distant units. The conditioned response, in other words, is entirely extinguished except for the single firing of one unit. Spontaneous recovery had not occurred during the 30-minute rest. Thirty re-conditioning trials were now given, and record 10 shows two results: (1) The unit which fired spontaneously before the onset of the light begins to fire at a rapid rate 100 ms after the light, followed by an increased background activity 100 ms later and then by a burst from nearby units. The duration of this major response was some 200 ms. Records 12 and 16 were made after extinction. The spontaneous unit of 16 is of particular interest in that its rate is not affected by the light and in that it seems clearly to be the same unit that was firing in records 1 and 10. (This latter point supports the belief that no shifting of the electrodes had occurred. It will be recalled that the rat's leg was so held that gross movements at the ankle and knee could hardly be made. Such great bursts of activity as are seen in records 3 and 10 occurred frequently without any observable movement of the leg.)

Figure 2 contains another type of conditioned response, viz., the conditioned speeding up of the firing of a single motor unit corresponding to a conditioned increase in tension of muscle fibers in the gastrocnemius. This record is one of those taken from an animal whose tibial nerve had been reduced in the number of functional fibers by cutting and teasing. The electrodes were so placed that a single nearby unit is clearly recorded as well as the activity of distant units. Whereas the distant units are thrown into activity by the light, the near unit is merely speeded up in its firing. At

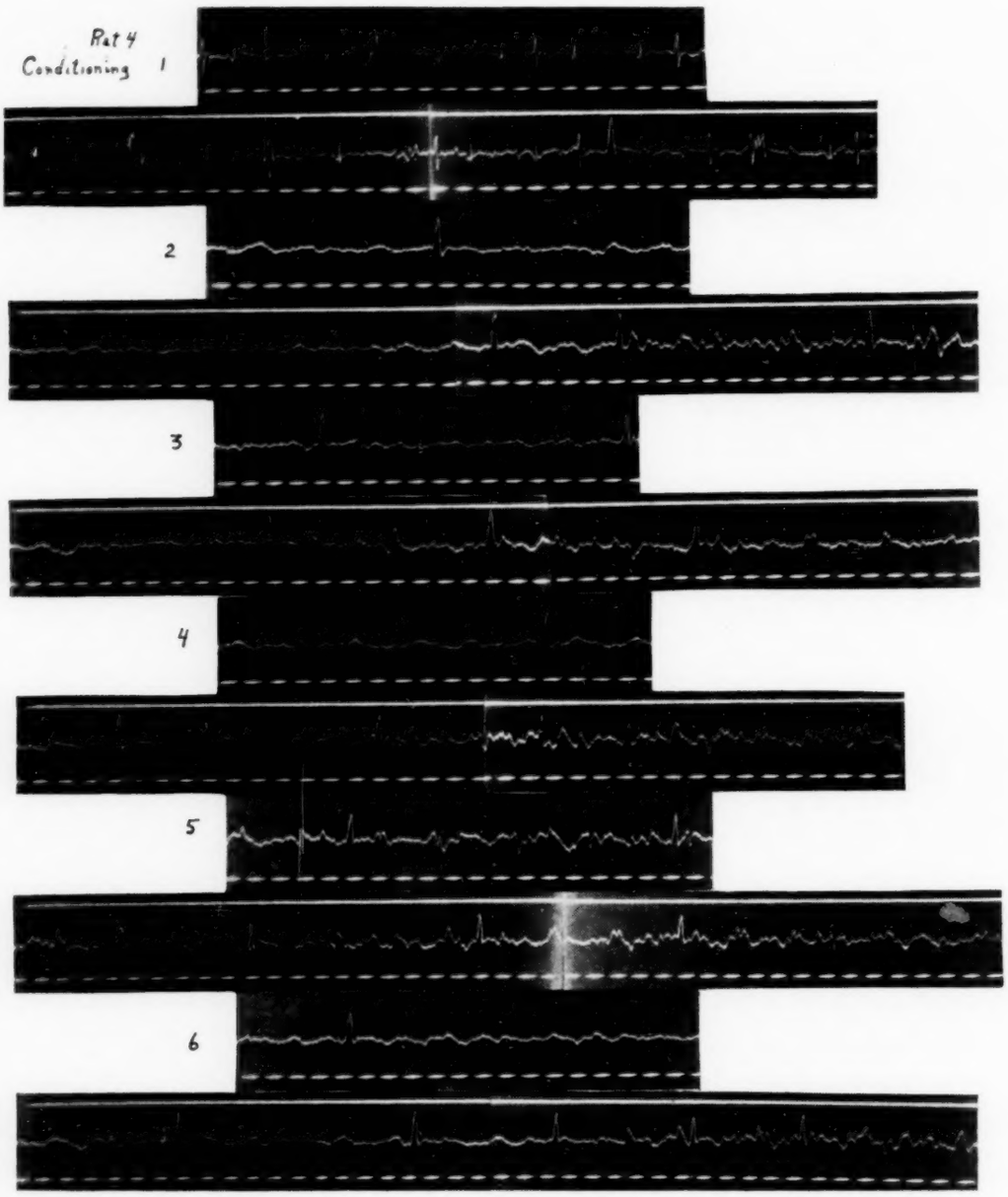

FIG. 2. Conditioning in rat 4

1, before conditioning; 2, after 15 conditioning trials; 5 conditioning trials were given before each of 3, 4, 5 and 6. The short part of each record, centered in the figure is before the light stimulus. The longer part of each record is continuous with the first part. Time in 10 ms.

the time that the records of Fig. 2 were made the rat had been conditioned and the response extinguished some dozen times over a period of 6 weeks. As a result the initial conditioned response appeared here in record 2 after only 12 paired presentations of light and shock. (The response might have appeared sooner had tests for it been made.) In record 1, Fig. 2, made before the present conditioning, there are two units firing spontaneously at regular intervals before the onset of the light. These units are unaffected by the light which, however, does activate a monophasic unit which fires twice, first with a latency of about 50 ms and again 195 ms later. Records 2–6 are successive stages of conditioning. Two points are to be noted: (1) There is a conditioned speeding up of the large monophasic unit to an interval of 50–60 ms from a rate of 90–120 ms or even longer as in record 2. (2) There is a conditioned appearance of distant summed units whose successive latencies are as follows: record 2, 255 ms; record 3, 125 ms; record 4, 95 ms; record 5, undetermined; and record 6, 260 ms.

Figure 3 presents the extinction of the responses just described. (The experiment, of course, was carried out without in any way disturbing the electrodes.) Records 7 through 11 show: (1) a decrease in the speeding up of the large unit which, in contrast to the conditioning records, is activated by the light rather than fired spontaneously; (2) an increase in the latency of the first appearance of this unit from 150 ms through 190 ms to 390 ms; and (3) an early extinction of the responses of distant units. Record 12, the first picture immediately after disinhibition, is negative; but record 15 shows the same spontaneous unit of the earlier pictures present and again speeded up by the light which has also reinstated the distant units.

Disinhibition.—The preceding paragraph and Figure 3 have already offered certain information on disinhibition. Figure 4 shows additional cases. Rat 6 had been conditioned twice before the session represented in Fig. 4 where record 4 is the second of the first two (consecutive) conditioned responses. The shift in the base line and the summed re-

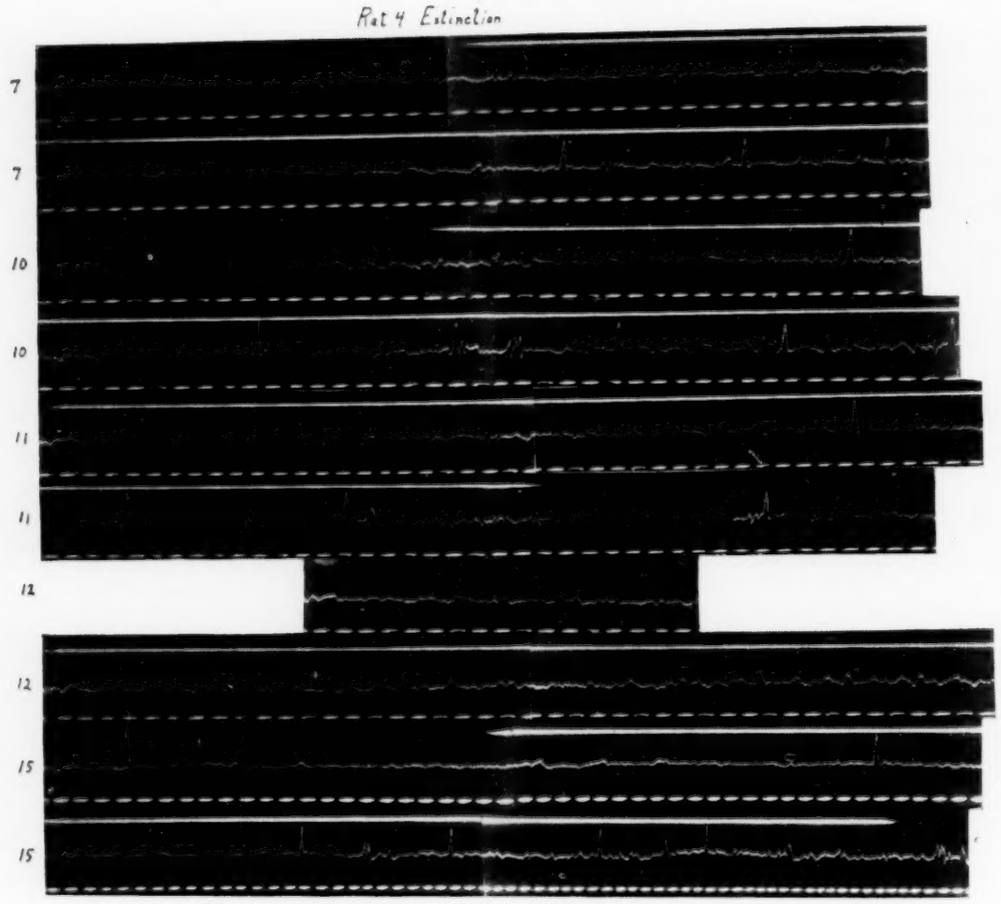

FIG. 3. Extinction in rat 4 of the response shown in Fig. 2

Between 6 of Fig. 2 and 7 of this figure, 10 extinction trials were given. (The records numbered alike are continuous and to be read from left to right.) 5 extinction trials between 7 and 8; 19 extinction trials between 8 and 10; 1 extinction trial between 10 and 11; record 12, first picture after disinhibition; record 15, 1.5 mins later.

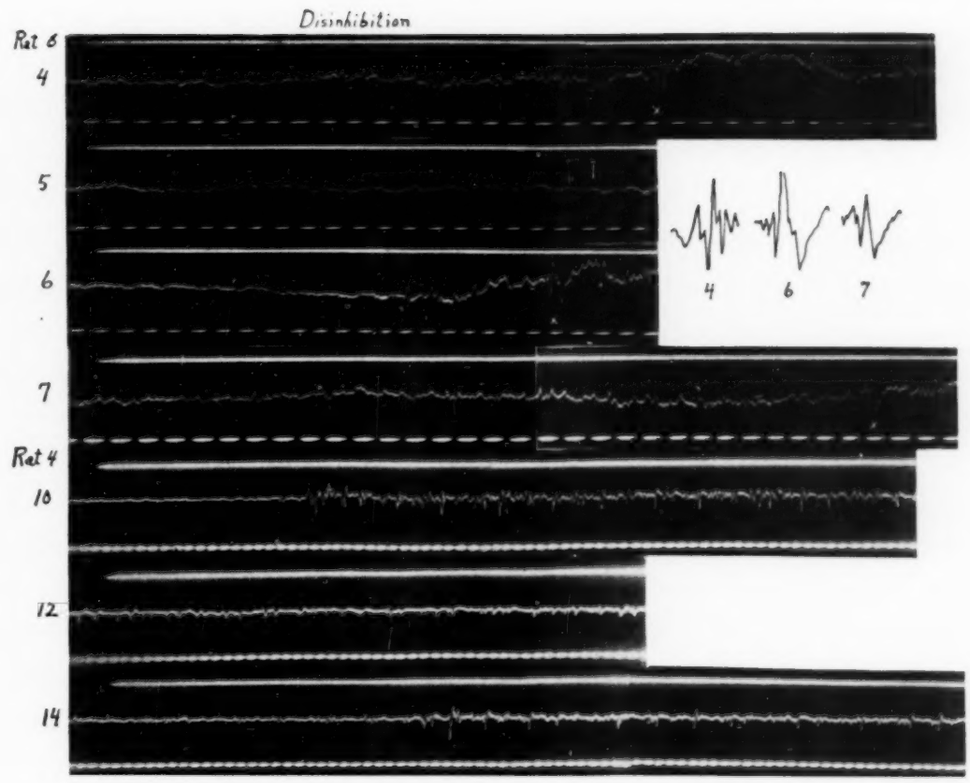

FIG. 4. Disinhibition

Rat 6: Record 4 was preceded by 15 conditioning trials. Between 4 and 5, 3 extinction trials were given. Between 5 and 6, rat disinhibited. Record 7, 30 secs after 6. The inset contains tracings made from projections of the portions marked x in records 4, 6 and 7. Time in 10 ms.

Rat 4: Record 10 was preceded by 65 conditioning trials and 12 extinction trials. Between 10 and 12, 6 extinction trials. One minute after 12, the rat was disinhibited. Record 14 was 1 min after disinhibition. Time in 10 ms.

sponses marked *x* occur with a latency of 220 ms. Three extinction trials resulted in no response to the light as shown in record 5. The rat was now pinched on the hind legs and, when the response to this stimulation had died down, the light was again presented. The result appears in record 6. Here the latency of the base line shift is 135 ms and that of the summed units is 200 ms. Thirty seconds later the unreinforced light was again presented with the result shown in record 7. There may be some distant response at 165 ms, but the summed response marked *x* now comes at a latency of 295 ms. The inset line-drawings are tracings made of the summed responses in records 4, 6 and 7 by projecting the film. Although a detailed analysis of the tracings in terms of single units is impossible, it seems reasonable to conclude that in record 6 disinhibition has reactivated some of the units of record 4, has added new units which sum in the middle of the response, and has failed to reactivate certain units at the close of the response. In tracing 7, where the response is on the way to extinction, the final portion of the activity in tracing 4 is still absent, the central portion is more reduced than in tracing 4, while the initial portion is much like the corresponding part of 4, although of lesser amplitude.

At the time that rat 4 was tested to give the results shown in Fig. 4, it had already been conditioned on four previous occasions. Record 10 was the last conditioned response photographed in the present test before extinction was complete. The light started a response at 160 ms, or at 185 ms if latency is read to the first large unit present. The response involved one unit which continued to fire regularly, another which fired only 3 or 4 times, and an activity of distant units which is unanalyzable. Record 12 shows complete extinction. Between records 12 and 14 the rat was pinched for disinhibition. The result, record 12, is that some of the old units were again activated and one apparently new unit, the first long spike, fired but once.

The general conclusion from the disinhibition records is that some of the same moto-neurones whose activity was extinguished are again excited by the light after disinhibition. This agrees with the finding of Prosser and Hunter on the

disinhibition of unconditioned reflexes. It is further in harmony with the view of those writers to the effect that extinction and disinhibition occur as central processes affecting the same synapses. Nothing in the present experiments indicates the character of these central processes. There seems, however, no objection to regarding the effect of extinction as a progressive decrease in excitability of the center or to regarding the effect of disinhibiting stimuli as an increase in excitability.

Summary.—The present experiments deal with conditioning, extinction and disinhibition of responses in the gastrocnemius muscle of the rat where light of 0.7 foot candles has been the conditioned stimulus and shock the reinforcing stimulus. Electric recording with concentric needle electrodes made possible the analysis of the records in terms of the responses of individual moto-neurones.

Conditioning may bring into activity individual units not before excited by the light or it may serve to increase the frequency of spontaneously firing units, a result which was not secured without conditioning. In the present experiments the latency with which these effects are produced tends to decrease as conditioning progresses. The records clearly show selective conditioning of the motor units in that near and distant responses are differently affected. This indicates, if proof is necessary, that nerve impulses do not flood indiscriminately over the neurones to a given muscle but that there is a nice selection which may result only in certain parts of a muscle or in certain ways of its functioning being conditioned.

Extinction presents a picture the reverse of that in conditioning. Individual units drop out, the conditioned speeding up of spontaneous units fails, and the latency of responses increases. Finally when the light no longer arouses a response, pinching the animal raises the excitability of the nerve centers to such a point that the light will again activate some of the formerly conditioned units and perhaps others as well.

To what extent does conditioning involve the making of new neural connections and to what extent does it involve

merely an increased excitability of existing connections? Prosser and Hunter found the same picture with respect to latency and individual units in the case of startle responses to sounds just above the threshold for leg movement and in the case of the same response aroused by a former sub-liminal sound rendered effective by pairing it with shock. Certainly these results make it appear that the 'conditioned' startle results only from an increased excitability of the centers involved in the unconditioned startle response. The present experiment offers a marked contrast to that by Prosser and Hunter in the following respects: (1) Startle responses where present may involve other motor units than those found in the conditioned response. For example, the motor unit set off as a startle response in record 1, Fig. 2, latency 50 ms, is the same unit whose rate of firing is conditioned later in the same figure; but this unit is not involved in the conditioned background responses of distant units. (2) The latency of the conditioned response is of an entirely different order of magnitude from that found in startle responses. And (3) the latency of the conditioned response changes during conditioning and extinction whereas that of the startle response remains constant. My own interpretation of these facts is that conditioning involves the utilization of neural centers, probably cortical in the normal animal, which are new in that they were non-functional in the startle response. One would expect them to be non-functional in such a response no matter what the intensity of stimulation might be since an increased intensity of stimulation could not be expected to increase response latency. To the extent that the motor units in the startle response are different from those in the conditioned response to that extent conditioning may even bring in new units from the ventral horn.

(Manuscript received July 14, 1937)

References

1. Bartley, S. H., Relation of intensity and duration of brief retinal stimulation by light to the electrical response of the optic cortex of the rabbit, *Amer. J. Physiol.*, 1934, **108**, 397–408.

2. Prosser, C. L., and Hunter, W. S., The extinction of startle responses and spinal reflexes in the white rat. *Amer. J. Physiol.*, 1936, **117**, 609–618.

HUMAN OCCIPITAL BRAIN POTENTIALS AS AFFECTED BY INTENSITY-DURATION VARIABLES OF VISUAL STIMULATION [1, 2]

BY RUTH M. CRUIKSHANK

The electrical activity of the occipital cortex in man as detected through the unopened skull has been shown to signalize aspects of cortical function related generally to certain states of the organism designated under the terms 'arousal' and 'attention' and more specifically to certain aspects of vision (**4, 5, 6, 9, 10, 23**). The present report is concerned with a preliminary investigation of the changes in the electrical activity of the occipital cortex in response to a uniform visual stimulus systemically varied in intensity and duration. Since intensity-duration functions have been fairly well worked out for the retinal processes (**1, 2, 3, 12, 13, 16**) this study was undertaken in order to determine to what extent occipital cortex potentials in man were determined by the known characteristics of the peripheral receptor.

Technique

The amplifier-oscillograph system permitting the simultaneous independent recording of potentials from as many as four pairs of electrodes is similar to that previously described by Jasper and Andrews (**19, 20**). The electrodes consisted of small chlorided silver discs with an inside depression of 5 mm diameter. Contact to the scalp was made through Cambridge Electrode Jelly. The silver discs were held in place on the scalp with collodion.

The electrode placements used in this study were over the occipital bone, with one lead in all cases estimated to be over the occipital pole of the cortex. Simultaneous records were usually taken from two bipolar leads placed in different positions over the same region in order to check the possibility of error due to different response from different parts of the cortex. A monopolar lead was also taken to check the possibility

[1] Abstract of thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Brown University, July 1936 (**21**).

[2] The writer wishes to express her gratitude to Dr. H. H. Jasper under whose direction the experimental work was carried out with the aid of a grant from the Rockefeller Foundation, and to Dr. H. L. Andrews and Professor Leonard Carmichael for their aid.

of interference artifacts from the bipolar recording (**18, 19**). A diagrammatic presentation of the electrode placements is given in Fig. 1 with the measurements as made from the posterior occipital protuberance (inion) and the point of suture of the occipital and parietal bones (lambda). Electrode *B* in each case was approximately over the occipital pole and was used as the monopolar lead with the two ears as the diffuse lead (*D*).

The subject was placed in a semi-reclining position in a sound proofed, electrically shielded room separated from the adjoining control rooms containing the stimulating and recording equipment. No auditory cues associated with the taking of records or the administering of the stimulus were present for the subject except as given over the telephone system from the control room. Light reached the subject's eyes through the wall by means of a two-inch iron pipe sealed at both ends with heavy plate glass. The light source was a 200 watt 16 mm movie projector unit with a camera shutter,

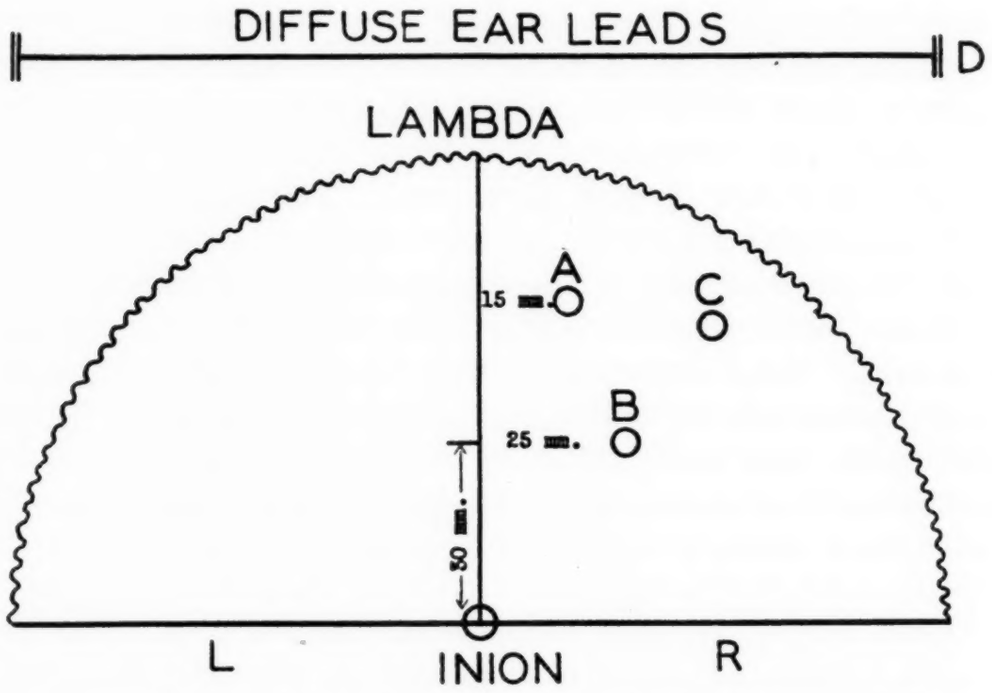

FIG. 1. Diagram of electrode placements over the occipital bone. *A*, *B* and *C* are 2 cms apart. *B* is estimated to be over the occipital pole of the cortex, a position usually found to be about 3 cms above the inion and 2.0 to 2.5 cms from the mid-line.

water filter, and frames for the insertion of Wratten neutral tint filters added in front of the projection lens.

A diffusing screen was placed over the subject's eyes and the light source adjusted to provide even illumination over the screen to eliminate points of fixation and the effect of different areas of stimulation. The maximum intensity of the light after it passed through the diffusing screen at the subject's eyes was about 10 millilamberts. This was about 6 log units above the minimal threshold of most of our subjects after they had been dark adapted for at least thirty minutes.

A signal of the exact beginning and end of each stimulus was obtained by placing a Weston photo-electric cell near the subject's head and connecting it through an independent amplifier to one of the oscillograph units recording simultaneously with the brain potentials. This also gave us a check on the reliability of the camera shutter which permitted durations of exposure from 5 ms to 2 seconds.

The five subjects selected for this study all presented a good resting spontaneous alpha rhythm. They were three graduate students in psychology at Brown University, one professor in psychology, and one nurse at the Bradley Home.

Each experimental session lasted from one to two hours. Twenty minutes dark adaptation was given before the administration of the first light stimulus and then three to five minutes allowed for readaptation between stimuli depending upon the intensity and duration of the stimuli employed. A preparatory signal, 'eyes open,' was given to the subject two to ten seconds before each stimulus. This preparatory interval was made variable for two reasons; (1) the attempt was made to flash the light during a burst of spontaneous activity, and (2) after two or three presentations of the preparatory signal at a constant interval before the light the brain potentials would become conditioned to react to the preparatory signal before the light flash. The auditory signal itself would have no appreciable effect on the brain potentials before this conditioning except perhaps to increase the amplitude and regularity (facilitation) of the spontaneous alpha rhythm if the subject had become a little drowsy between stimuli. The preparatory signal was necessary in order to make the position of the eyes and the general attitude of the subject more constant from one stimulus to the next.

Results

The most prominent effect of a light stimulus administered under these conditions was a depression or blocking [3] of the spontaneous ten-cycle alpha rhythm.

The blocking time, that is the time between the incidence of light to the eye and the last alpha wave, may usually be measured with a fair degree of precision if the measurement is made to the peak of the last detectable alpha wave. It was found, however, as noted in a previous study (**22**) that this blocking time is not always a simple measure since quite frequently the light stimulus is seen to *initiate* one or two waves before the dropping out of all rhythmic potentials. These evoked cortical potentials, commonly observed in animal studies (**8, 24**), are not easily detected through the skull, but when they do appear they serve to complicate the measurement of blocking time as such since the evoked potentials are not easily distinguished from those of the spontaneous rhythm.[4] When the 'on' effects are detectable

[3] The term 'blocking' is here used merely to designate the dropping out of detectable electrical potentials as opposed to the term 'depression' which implies an actual decrease in rhythmic activity. Since the apparent dropping out of electrical activity may be due to a desynchronization process, as well as to an actual inhibition, it is felt that the term 'blocking' is less suggestive of a true decrease in activity than is the term 'depression.'

[4] The distinction between the 'Aktionsströme' and 'Eigenströme' made by Kornmüller is applicable here to potentials from the human cortex.

they provide a more definite indication of the cortical response to light stimulation than blocking itself. In some of our records we were able to distinguish quite clearly the blocking effect from the evoked potentials due to differences in form and latency so that we conclude that the two phenomena may be somewhat independent. Further evidence for their independence is shown in records in which the light flash was presented at a time when there was a 'spontaneous' depression of the alpha rhythm; the 'on' effect appeared regularly regardless of the presence or absence of spontaneous activity. Fig. 2 shows a record in which the spontaneous activity dropped out before the light flash due to conditioning to the preparatory signal. The evoked potentials are clearly present for the maximum intensity.

The form of the 'on' effects was most readily observed from the monopolar leads. It consisted of one or more waves about 0.1 seconds in duration followed by a longer lasting positive wave. The significance of this sequence of potential disturbances, observed both in the cat and in man, has been discussed by Jasper (**17**). We have not observed a clear 'off' effect in the studies here reported. In those cases where the blocking time could be distinguished from the latency of the 'on' effect, or implicit time according to the terminology of Bartley (**7**), a separate series of measurements was made for each effect. In most of the records, however, blocking time was measured from the incidence of light to the peak of the last detectable potential, thus including, perhaps, a sequence of evoked potentials.

The duration of the blocking effect, or recovery time, is not so definite in measurement as the blocking time since the spontaneous alpha rhythm appears to return more gradually. The measurements of recovery time in this study will be taken from the end of the blocking time to the first detectable alpha potential following the blocked period. Measurements of blocking and recovery time were not always the same from different simultaneous leads, so that it will be necessary for us to present the measurements from the different leads designated according to the diagram in Fig. 1.

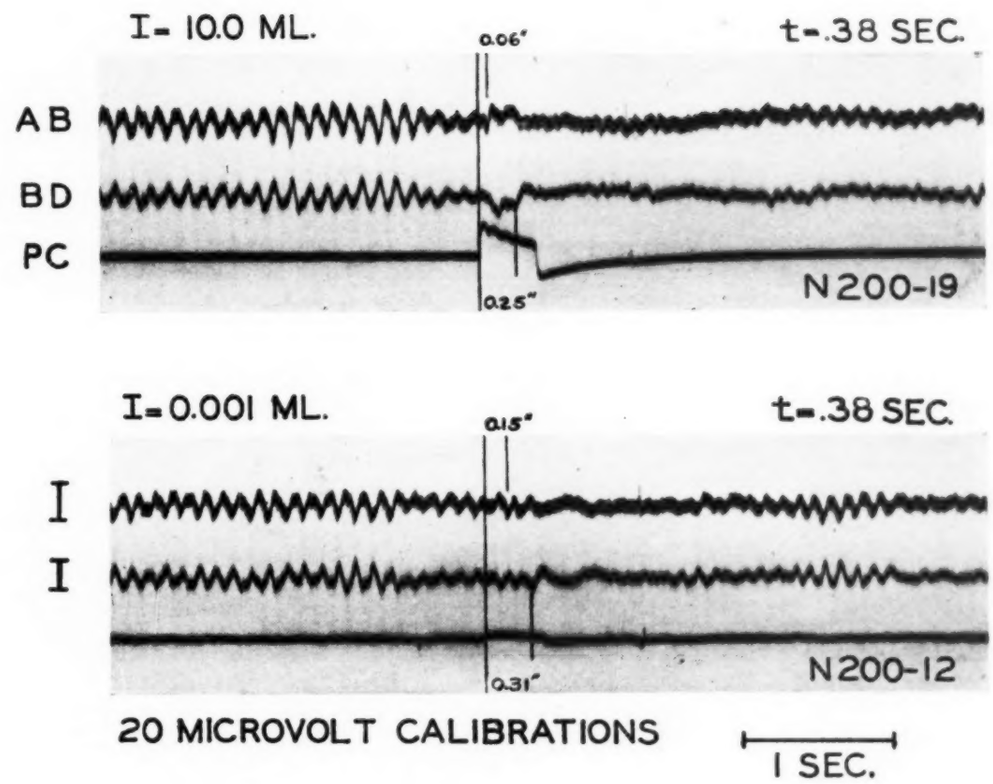

FIG. 2. Evoked potentials in response to intensities of 10.0 mls and 0.001 ml with a constant exposure time of 0.38 sec. Note the increase of implicit time from 0.06 to 0.15 sec from the bipolar leads *AB*. An apparent blocking time of 0.25 and 0.31 sec is found from the monopolar leads *BD* but this is actually measured to the end of a series of evoked potentials.

Blocking Time as a Function of Intensity

The results from three subjects with variations in intensity of six log units at constant duration of 0.34 sec, 0.17 sec, 0.02 sec, are given in Table 1. Measurements from simultaneous bipolar and monopolar records from the right occipital region are given in each case.

These results indicate an inverse relationship between blocking time and stimulus intensity. The greatest variation in blocking time and the most regular series of measurements was obtained from Subject 4 who showed variation from 119

TABLE 1

BLOCKING TIME AS A FUNCTION OF INTENSITY

	Duration 340 ms		Duration 170 ms						Duration 20 ms	
Subject.....	3		3		4		5		3	
Leads.....	R AB	R BD	R AB	R BD	R AB	R BD	R AB	R BD	R AB	R BD
Log I. (in mls)										
1	210	167	176	221	119	178	191	205	249	176
0	194	175	176	221	163	178	205	205	294	206
−1	216	197	323	235	238	238	220	235	294	191
−2	162	227	221	273	416	356	235	235	367	265
−3	297	230	235	294	470	356	264	294	382	308
−4	311	270	265	294	760	415	382	294	515	323
−5					920	920	662	588		

ms to 920 ms with variations in intensity of 7 log units above her threshold. The results from the other subjects are not so regular nor so striking partially due to difficulties in making accurate measurements but also due to variability in the blocking effect itself.

Blocking times from monopolar and bipolar records for Subject 4 as plotted against the logarithm of the stimulus intensity is shown in Fig. 4. This curve shows a striking similarity to the dark adaptation curve presented by Hecht (**16**) from the results obtained by Haig and Wald on human thresholds with white light stimulating the eye as a whole. The two sections of the curve are probably due to the differen-

tial function of the rods and the cones as reflected in determining the amount of excitation to the optic nerve which in turn determines the cortical blocking time. It is interesting to note that the results from threshold measurements according to Haig and Wald correspond so closely to those obtained from blocking time with supra-threshold stimuli. Subject 5 did not show this break in the curve (Fig. 4).

Stimuli presented at intensities just below the reported threshold would not produce a complete blocking of the spontaneous rhythm. However, in two experiments an appreciable depression of the alpha rhythm was noted following a flash of light which the subject reported as not seen (Fig. 3). This effect was checked by repeated stimuli at and just below the threshold and it was found that sub-threshold stimuli, as judged by subjective report, would consistently produce detectable changes in the brain potentials. Definite evoked potentials were also produced in another subject with 'sub-threshold' stimuli.

Blocking Time as a Function of Duration

At durations of above 0.2 seconds blocking times were fairly constant with the constant intensity of stimulus, especially for the maximum intensity used (10 mls). When the duration of exposure is decreased below 0.1 to 0.2 sec. (critical duration) there was an increase in the blocking time. Since the camera shutter used did not give very reliable results below ten milliseconds our data is incomplete at the short exposure times where it seems to be the most important in order to work out the complete relationship between blocking time and exposure time. The measurements which could be made with a fair degree of accuracy are shown in the following table (Table 2). The critical duration appears to be between 0.1 and 0.2 second. This is roughly of the same order of magnitude as the values reported by Graham and Margaria (**13**) for liminal subjective thresholds to stimulation of small areas. The general nature of the relationships found between blocking time and stimulus duration in the present experiments in which the entire visual field was

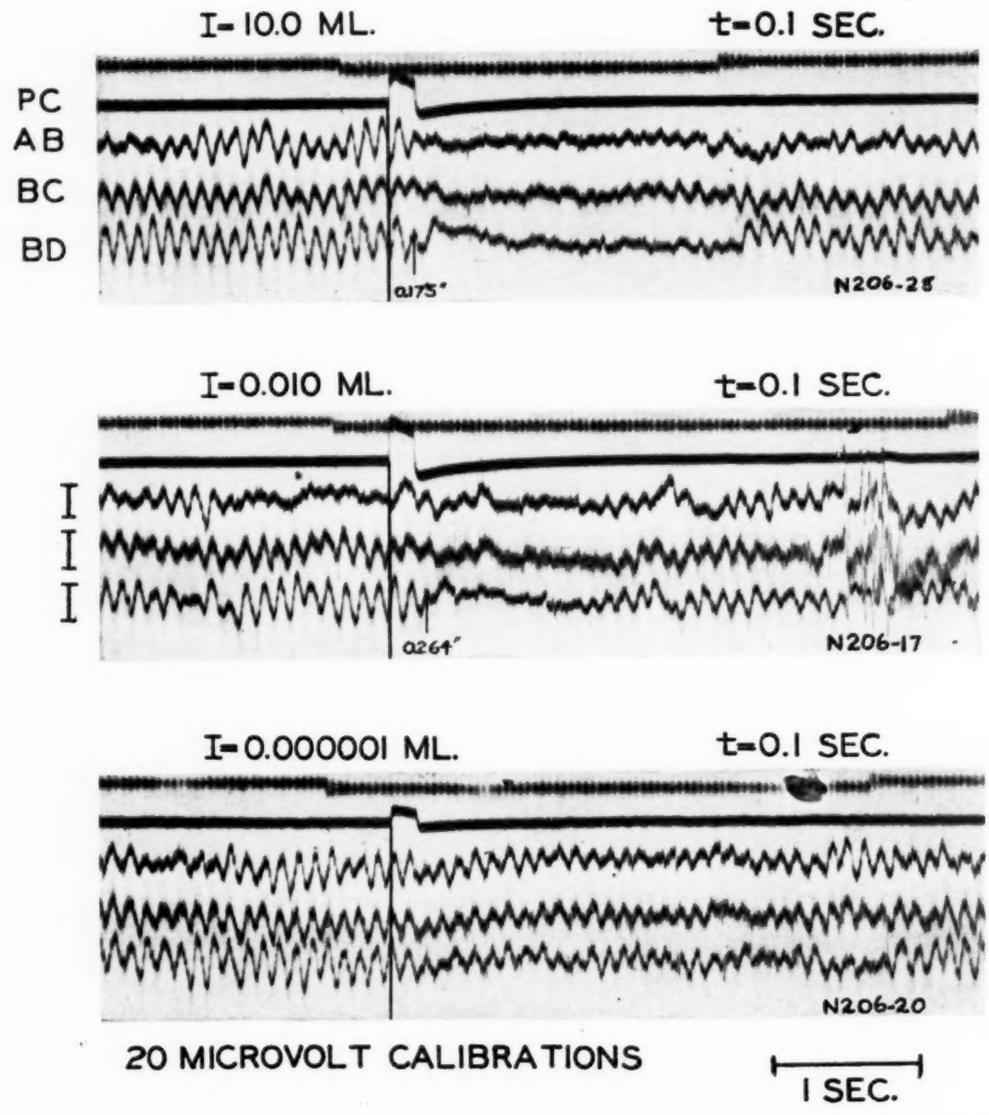

FIG. 3. Blocking time at intensities of 10.0, 0.010, and 0.000001 ml, the latter being below the visual threshold according to subject's report. Note that a simple blocking of the alpha rhythm in about 0.2 sec appears to occur in the first film, bipolar leads *AB*, while in the next film the record from the same leads is blocked before the flask of light and five waves follow the stimulus as though they were evoked potentials. In the last film incomplete blocking is shown in response to a 'subthreshold' stimulus.

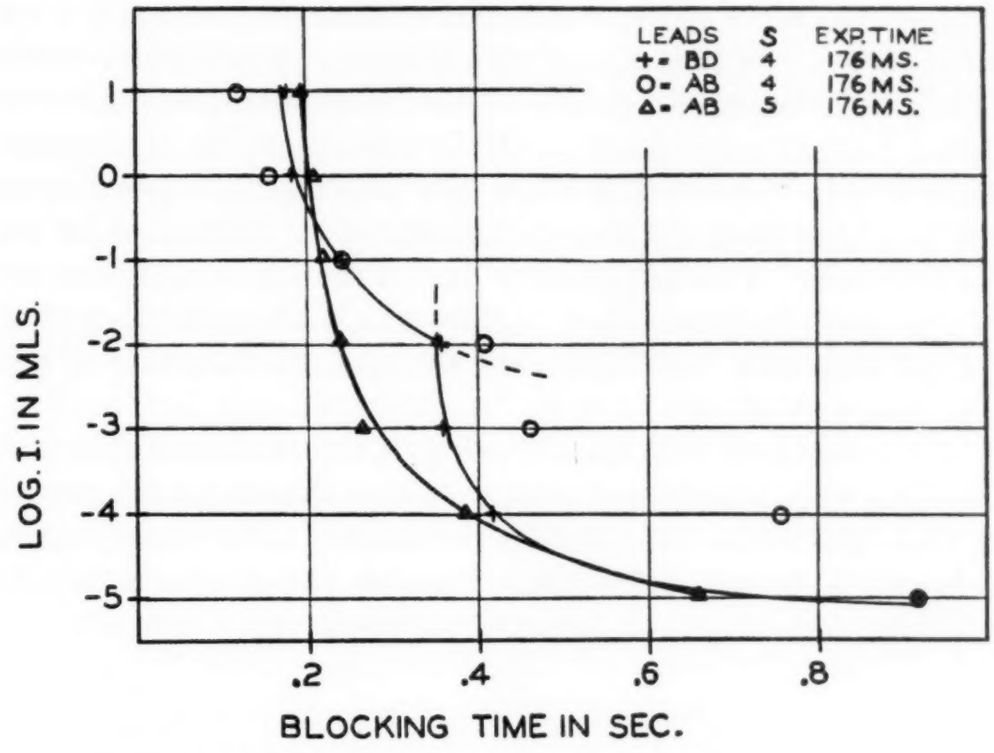

FIG. 4. Blocking time as a function of Log I. The double curve through the crosses represents one set of measurements from monopolar leads on subject 4. The circles are points from another set of measurements on the same subject taken from bipolar leads. The smooth curve through the triangles represent a series of measurements from bipolar leads on subject 5.

TABLE 2

BLOCKING TIME AS A FUNCTION OF DURATION (IN MS.)

	Intensity 10.0				Intensity 1.0					Intensity 0.01				
Subject.....	1		2		4		5			3			5	
Leads.....	R AB	L AB	R AB	R BD	R AB	R BD	R AB	R BC	R BD	R AB	R BD	R AB	R BC	R BD
Duration in ms														
1600	270	229	106	106										
640			106	106	154	163								
340			106	160			206	191	220	265	249	206	256	235
170	162	208	162	151	163	178	206	213	206	275	367	235	262	228
40			186	141	180	188	235	206	206	265	265	250	279	242
20	297	256	200	168	194	188				265	221			
10			213	186										
5	297	297	215	240	190	188	250	294	235	323	367	323	344	294

illuminated serve to show that this cortical response may vary with duration in accordance with known characteristics of the retina but the precise nature of this relationship will have to await further experiments. It is evident from the results presented in Table 2 that there may be irregular variations in the blocking time apparently unrelated to variations in exposure time. This is probably due to the inadequate control of the complex of secondary factors which affect blocking time (visual attention, etc.) and tend to mask the function of retinal processes alone.

In accordance with these findings it follows that a constant blocking time is obtained with a shorter duration of exposure at high intensities than at low intensities. For example, we obtained a constant blocking time of 175 ± 15 ms at the following intensity and duration values:

I	*t*	*It*
0.3 ml	0.005	0.0015
0.15 ml	0.010	0.0015
0.075 ml	0.020	0.0015
0.003 ml	0.640	0.0019

It appears that, for durations below 0.1 to 0.2 secs, Bloch's law (It = C) is again confirmed in this study and that cortical response, obtained under carefully controlled conditions, may give a reliable indication of retinal events since this It relationship has been shown to hold for the excised eye (**1**, **2**, **14**, **15**).

Evoked Potentials as a Function of Stimulus Intensity

In one subject a clearly identifiable evoked potential could be detected in response to each flash of light for intensities down to about two log units above his subjective threshold. The magnitude of this response varied with Log I. according to a sigmoid curve with a fairly linear relation between 0.01 and 1.0 millilambert.

The latency (or 'implicit time') of this evoked potential varied also with intensity in a manner similar to that already described for blocking time. In some records this potential was preceded by an earlier potential as shown in the first record of Fig. 2. In this record, the peak of the first response

to a flash of light 0.38 sec in duration at an intensity of 10 mls occurred after an 'implicit time' of about 0.06 sec. The series of records from this subject, giving implicit times between 0.06 and 0.20 sec, was one of the few which gave results which make possible a comparison with the findings of Bartley (**7**, **8**) on the optic cortex of the rabbit. The range of intensities ordinarily employed by Bartley was about one hundred times that employed in the present experiments. In one series of experiments on the effect of area, however, he illuminated the whole eye, as in our experiments, and used intensities below ten candles per square foot (**8**). In this series of experiments variations in implicit time between 0.050 and 0.095 sec were obtained for intensity changes between about 0.2 and 4.6 candles per square foot. This corresponds very closely to the variations we have observed in implicit time measured to the first evoked potential with variations over the same range of intensities. It appears, therefore, that implicit time for cortical response in man may be of the same order of magnitude as that observed by Bartley for the rabbit when similar conditions of experimentation and similar methods of measurement are employed. Blocking time, however, is a different phenomenon and cannot be compared directly with implicit time.

Recovery Time as a Function of Intensity and Duration

In some of our experiments a decrease of intensity below 10 mls and a decrease in duration below 0.2 sec was associated with a decrease in recovery time but this relationship was not always consistent and would occasionally be reversed, that is, a longer recovery time would be associated with the shortest exposure time or the weakest intensity. An example of these results is given in the following tables on page 636.

It appears that recovery time is not so readily controlled by intensity-duration variables under the same conditions as is blocking time. The fact that a long recovery time is frequently associated with stimuli in the vicinity of the subjective threshold suggests that the persistence of the blocking effect may be due to some re-enforcement from whatever

TABLE 3

RECOVERY TIME AS A FUNCTION OF INTENSITY (IN SECS.)

Subject	4		5		
Leads	R AB	R BD	R AB	R BC	R BD
Log I. (in mls)					
1	1.75	1.96	2.00	2.02	1.67
0	1.43	1.69	1.18	1.21	1.04
−1	0.89	1.10	1.60	1.98	1.54
−2	1.07	1.40	1.23	1.36	1.03
−3	0.86	1.10	1.06	1.06	1.23
−4	0.95	1.45	1.38	2.23	1.76
−5			1.47	5.34	5.44

TABLE 4

RECOVERY TIME AS A FUNCTION OF DURATION

Subject	1 10 ml	4 0.1 ml	5 0.010 ml
Duration (in ms)			
1600	2.39″		
640	2.10	1.50″	
340	1.98		1.43″
176	1.54	1.70	1.47
40	1.47	0.84	1.66
20	1.22	1.18	
10	1.24		
5	1.02	1.20	1.73

psycho-physiological processes might be involved in increased 'visual attention' or the 'attempt to see.'

Prestimulation and Poststimulation Alpha Frequencies

The frequency of the alpha waves as they recover from being blocked by the light stimulus is somewhat higher than the prestimulation frequency if one uses as a measure of poststimulation frequency the first five alpha waves which appear. This effect is noticeable chiefly with the greater light intensities and decreases as the intensity reaches threshold value. The relationship between intensity and percentage increase in alpha frequency for two subjects is given in the following table:

TABLE 5

ALPHA FREQUENCY INCREASE AS A FUNCTION OF INTENSITY

Subject.....	4			5		
Log I.....	F_1	F_2	Percent Increase	F_1	F_2	Percent Increase
1	9.4	11.0	17	9.0	12.7	41
0	9.8	11.0	12	9.0	10.0	11
−1	9.6	10.8	12	9.0	10.6	18
−2	9.6	10.1	5	9.0	9.2	2
−3	9.6	10.0	4	9.1	9.2	1
−4	9.3	9.7	4	9.0	9.7	8
−5	9.3	9.4	1	9.0	9.1	1

This temporary acceleration of the alpha rhythm following its blocking by the visual stimulus is related to other excitatory conditions which cause small changes in alpha frequency (**11**, **17**). It is interesting to note that the limits of acceleration are rather narrow and that blocking occurs before frequencies higher than twelve or thirteen per second are reached under the conditions of these experiments. The occipital cortex appears to be incapable of maintaining its synchronized beat with a further increase in excitation.

Anticipatory Response

It has been mentioned above that it is necessary to vary the interval between the auditory preparatory signal and the exposure of the light to avoid anticipatory blocking of the alpha rhythm coincident with or even previous to the visual stimulus. Since the present investigation was not concerned with conditioning we have not presented the results obtained from such experiments as were obviously affected by this complication. In the preliminary experiments it was not uncommon to find no systematic relation between blocking time and the intensity-duration variables of the stimulus due to 'spontaneous' blocking. This effect was minimized by a greater variation of the preparatory interval and by flashing the light when a train of spontaneous alpha potentials was observed in the viewing screen.

This anticipatory blocking shows that, even though the occipital cortex potentials may reflect certain quantitative

aspects of their visual afferent impulses, their control may be taken over by afferent impulses from other sense modalities.

Evoked potentials were not affected by anticipatory response as was the blocking of spontaneous activity. In some cases the alpha rhythm would be absent at the time the light was flashed due to anticipatory blocking but the evoked potentials followed the stimulus as usual.

Discussion

The fact that the cortical response time, as indicated by potentials recorded through the unopened skull, can be varied with the intensity and duration of the stimulus in a manner similar to the variations observed in latency of optic nerve response to retinal illumination suggests a close relationship between retinal and cortical events. It is only by a very careful control of experimental conditions and by some selection of records that such a relationship can be demonstrated. Complex central processes concerned with visual attention and the afferent impulses from other sense fields may dominate the picture to such an extent that a cortical response which follows quantitative variations in the illumination of the eye is not easy to reveal. The electrical response of the cortex is comparable in this respect to the verbal report of visual thresholds since in such experiments also extraneous factors must be carefully controlled to obtain reliable results.

The discrepancy between the intensity which will elicit the verbal report of threshold illumination and a stimulus which will produce a detectable change in the occipital potentials should be investigated further. It appears that 'conscious' aspects of the visual process were not closely correlated with electrical signs of cortical response, the latter being apparently more sensitive than verbal report as a sign of threshold illumination of the eye.

Speculation in regard to the extent to which the retinal processes are responsible for the cortical response times obtained in these studies will be deferred until it is possible to obtain more direct evidence of retinal response simultaneous with the cortical potentials.

Conclusions

1. Two components of the electrical response of the human occipital cortex to light stimulation can be detected through the unopened skull; the blocking of spontaneous alpha potentials and the production of evoked potentials or 'on' effects.

2. The evoked potentials, although more difficult to detect because of their confusion with spontaneous activity and their more restricted localization, give a more stable response to light stimulation since they may occur irrespective of the presence or absence of spontaneous activity and are less easily affected by extraneous factors such as conditioning to the preparatory stimulus and visual attention.

3. Evoked potentials increase in magnitude according to a sigmoid relation to the logarithm of stimulus intensity.

4. Implicit time, as measured to the peak of the first evoked potential, may be varied between 0.06 and 0.15 sec with variations in intensity of illumination to the whole eye between 10.0 and 0.001 millilamberts which is in accord with somewhat similar results obtained by Bartley from the optic cortex of the rabbit.

5. Blocking time, which often includes one or more evoked potentials, may be varied between about 0.10 and 0.90 second in an inverse relation to intensity of illumination of the whole eye ranging from 10.0 to 0.000001 millilamberts. In some experiments the curve of blocking time log I showed a distinct break at about three log units above threshold which was attributed to the differential sensitivity of the rods and cones of the eye as reflected in the series of latencies involved in the course of excitation from the retina to the cortex.

6. Blocking time shows an inverse relation to stimulus duration below a critical duration between 0.1 and 0.2 second.

7. Preliminary results indicate that the reciprocity law relating exposure time and intensity ($It = C$) may be valid in determining a constant blocking time for exposure times below the critical duration.

8. Recovery time of the alpha rhythm after its blocking by uniform light stimuli shows a general tendency to be

longer with the higher intensities but this relationship is not consistent and is often reversed especially at intensities near threshold illumination where 'visual attention' or 'the attempt to see' may prolong the blocking effect.

9. The frequency of the occipital alpha rhythm as it returns from the effect of visual stimulation may be increased from twenty to forty percent of its prestimulation value at the maximum intensities used (10 mls). The amount of increase in frequency following stimulation decreases to only one or two percent at near threshold intensities.

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References

1. Adrian, E. D., and Matthews, R., The action of light on the eye: I. Discharge of impulses in the optic nerve and its relation to the electric changes in the retina, *J. Physiol.*, 1927, **63**, 378–414.
2. Adrian, E. D., and Matthews, R., The action of light on the eye: II. Processes involved in retinal excitation, *J. Physiol.*, 1927, **64**, 279–301.
3. Adrian, E. D., and Matthews, R., The action of light on the eye: III. Interaction of retinal neurons, *J. Physiol.*, 1928, **65**, 273–298.
4. Adrian, E. D., and Matthews, B. H. C., The Berger rhythm: potential changes from the occipital lobes in man. *Brain* 1934, **57**, 355–384.
5. Adrian, E. D., and Yamagiwa, K., The origin of the Berger rhythm, *Brain*, 1935, **58**, 323–351.
6. Bagchi, B. K., The adaptation and variability of response of the human brain rhythm, *J. Psychol.*, 1936, **3**, 463–485.
7. Bartley, S. H., Relation of intensity and duration of brief retinal stimulation by light to the electrical response of the optic cortex of the rabbit, *Amer. J. Physiol.*, 1934, **108**, 397–408.
8. Bartley, S. H., The time of occurrence of the cortical response as determined by the area of the stimulus object, *Amer. J. Physiol.*, 1935, **110**, 666–674.
9. Berger, H., Über das Elektrenkephalogram des Menschen, *J. Psychol. u. Neurol.*, 1930, **40**, 160–179.
10. Durup, G., et Fessard, A., L'électrencéphalogramme de l'homme. Données quantitatives sur l'arrét provoqué par des stimuli visuels ou auditifs, C. r. Soc. Biol., 1936, **122**, 756–758.
11. Durup, G., et Fessard, A., L'électrencéphalogramme de l'homme. Observations psycho-physiologiques relatives a l'action des stimuli visuels et auditifs, *Année Psychol.*, 1935, **36**, 1–35.
12. Graham, C. H., Vision: III. Some neural correlations, *Handbook of General Experimental Psychology*, Ed. by C. Murchison, Worcester, Mass., Clark Univ. Press., 1934, 829–879.
13. Graham, C. H., and Margaria, R., Area and the intensity-time relation in the peripheral retina, *Amer. J. Physiol.*, 1935, **113**, 299–305.
14. Hartline, H. K., Intensity and duration in excitation of single photoreceptor units, *J. Cell.* and *Comp. Physiol.*, 1934, **5**, 229–247.

15. HARTLINE, H. K., AND GRAHAM, C. H., Nerve impulses from single receptors in the eye, *J. Cell.* and *Comp. Physiol.*, 1932, **1**, 277–295.
16. HECHT, S., Vision: II. The nature of the photoreceptor process, *Handbook of General Experimental Psychology*, Ed. by C. Murchison, Worcester, Mass., Clark Univ. Press, 1934, 704–828.
17. JASPER, H. H., Cortical excitatory state and synchronism in the control of bioelectric autonomous rhythms, *Cold Spring Harbor Symp. Quant. Biol.*, 1936, **4**, 320–338.
18. JASPER, H. H., Electrical signs of cortical activity, *Psychol. Bull.*, 1937, *34*, 411–481.
19. JASPER, H. H., AND ANDREWS, H. L., Human brain rhythms: I. Recording techniques and preliminary results, *J. Gen. Psychol.*, 1936, **14**, 98–126.
20. JASPER, H. H., AND ANDREWS, H. L., Electroencephalography: III. Normal differentiation between occipital and precentral regions in man, *Arch. Neurol.* and *Psychiat.*, 1937, (in press).
21. JASPER, H. H., AND CRUIKSHANK, R. M., Variations in blocking time of occipital alpha potentials in man as affected by the intensity and duration of light, *Psychol. Bull.*, 1936, **33**, 770–771.
22. JASPER, H. H., AND CRUIKSHANK, R. M., Electroencephalography: II. Visual stimulation and the after-image as affecting the occipital alpha rhythm, *J. Gen. Psychol.*, 1937, *17*, 29–48.
23. JASPER, H. H., CRUIKSHANK, R. M., AND HOWARD, H., Action currents from the occipital region of the brain in man as affected by variables of attention and external stimulation, *Psychol. Bull.*, 1935, **32**, 565.
24. KORNMÜLLER, A. E., Die Bioelektrischen Erscheinungen Architektonischer Felder der Grosshirnrinde, *Biol. Revs.*, 1935, **10**, 383–426.
25. LOOMIS, A. L., HARVEY, E. N., AND HOBART, G., Electrical potentials of the human brain, *J. Exper. Psychol.*, 1936, **19**, 249–279.

A STUDY OF DIFFERENTIAL PITCH SENSITIVITY RELATIVE TO AUDITORY THEORY [1]

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According to interpretations of the Wever-Bray effect, the auditory mechanism functions primarily for the conduction of sound waves to the auditory nerve, which transmits them unaltered in pattern to the cerebral hemispheres. Thus, tonal analysis in the cochlea may or may not be present. Ruckmick, (1) in his latest review of the field of audition, cautions against a too-close correspondence between physiological determinants, such as Wever and Bray obtained, and psychological data; he is among those who conclude that mental auditory sensation can not be assumed to follow directly from electrical acoustical effects.

The experiments by Culler, Finch, and Girden (2) with trained dogs led them to the conclusion that tests of hearing are the only reliable basis for the interpretation of a given physiological phenomenon. Merely because such phenomena have been observed in connection with the auditory mechanism does not warrant an inference for its actual acoustic value.

Recently, studies on the pathology of tone deafness in humans (3) and the relationship of physiological phenomena (in animals) to auditory stimuli (4, 5) have presented direct evidence for tone localization in the cochlea. The correspondence of frequency-localization on the basilar membrane, however, is not specific, and for the region of low tones the evidence is meager. These studies make it increasingly apparent that, in such an intricate hydrodynamic structure as the cochlea, selective response can not be explained merely by principles of sympathetic resonance. It has been the

[1] Part of a dissertation presented in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

purpose of the present investigation[2] to obtain precise information regarding pitch sensitivity at a single frequency level which could be used as a factor in an explanation of auditory nerve excitation and conduction. Pitch thresholds were determined under the following conditions: (1) Supraliminal, medium, and loud sensation levels; (2) Loudness inequality of the tonal stimuli; (3) Time intervals of 1, 10, 30, and 60 seconds between members of paired stimuli of equal loudness; (4) Time intervals of 1, 10, and 30 seconds between members of paired stimuli of unequal loudness.

Thus it was proposed that changes in experimental technique would produce corresponding changes in acuity for pitch which could be interpreted as evidence of the mechanism for frequency analysis. The chief emphasis has been to develop a rigorous technique for the production and reception of as nearly a pure, constant stimulus as the present status of the physical sciences would permit, and to obtain information for pitch thresholds at the frequency level of 256 cycles per second.

Perhaps the most difficult phase of any problem in physiological acoustics is the production of a suitable stimulus. It is indeed a paradox that, surrounded as we are by a veritable universe of vibrating motion, the ideal sound for experimental purposes does not exist naturally. Purity of tone, characterized by a single frequency and steady loudness, together with variability of tone-pitch and loudness are the requisites to be sought for in an auditory stimulus but which have been attained only in part. Helmholtz proved conclusively that most instruments generate tones which are very complex and are characterized by the given pitch predominating over the component ones. Thus, even the simplest tone occurs as a "pitch-blend" and depends upon the relative strengths of the partial pitches which make it up. While the harmonics constitute the greatest source of impurity, the methods of activation and cessation of the tone introduce disturbing factors which are with difficulty eliminated. Consequently, of the several types of sound generators possible, only a few

[2] Professor Carl R. Brown supervised the study and designed the apparatus.

are capable of producing a tone suitable for physiological acoustics.

During the past two decades there has been an increasing tendency in physiological acoustics to utilize the principles of vibrating plates and diaphragms for sound generators. Wien (**6**) and Guernsey (**7**), in their work on liminal sound intensities in 1903 and 1922 respectively, were apparently among the first investigators to use an audion oscillating circuit and telephone receivers in a psychological study. As early as 1894, however, the physicist Rayleigh (**8**) employed this type of generator to determine threshold intensities for frequencies up to 768 d.v.

In 1931, Shower and Biddulph (**9**), employing heterodyne oscillators, modulators, and amplifiers, together with specially constructed receivers, determined pitch sensitivity at various frequencies and loudness levels. Electrical filters of the band-pass type were employed 'to eliminate the harmonics due to the non-linearity of the oscillator and amplifier circuits, and the extraneous sounds introduced by the power supply.' Acoustic wave filters to insure purity of output from the receivers, however, were not included in the apparatus.

Recently, Snow (**10**), using an elaborate electrical sound generator similar to that employed by Shower and Biddulph, has studied the effect of loudness upon pitch at frequencies from 75 to 1,000 cycles per second. Although the louder of two tones was usually judged to have the lower pitch, Snow obtained wide variations in the results for different observers and for the same observer on different occasions. The greatest shift in pitch was for the frequency of 100 cycles per second; its apparent pitch was lowered by as much as 50 percent for extreme loudness levels. Very little change in pitch was found at 1,000 cycles per second.

Apparatus

The sound generators used in the present investigation were mechanically activated tuning forks. The frequency of the constant pitch fork was 256 dv/sec; that of the variable pitch fork was some 32 dv/sec higher. By placing different U-shaped pieces of brass over the ends of the prongs of the variable fork, its frequency was made to differ from the constant pitch fork by gradations of 0.25 dv/sec up to 2 dv/sec, and

by gradations of 0.5 dv/sec from 2 to 7 dv/sec. These frequency differences were timed by the method of counting beats.

Each tuning fork was placed in a separate double-walled box, the outside surface of the inner wall and the inside surface of the outer wall being covered with thick hair felt. Between the two walls was a four-inch dead air space. These precautions were necessary to avoid undue dissipation of the energy of the forks and to exclude noises from the environment.

From each sound box extended a brass pipe of three-eighths inch inside diameter; these tubes conducted the sound to an adjoining sound-proof room where the observations were made. Provision for equating the loudness of the forks was made in these tubes by the insertion of brass plates containing holes of various diameters. Inside the sound-proof room, the tones passed through an acoustic filter, and at proper intervals were allowed to continue through a six-inch air valve to the ear of the observer. A three-cushion head rest enabled the subject to hold his ear comfortably and in a fixed position against the end of the sound tube. The tuning forks were controlled electrically by a motor driven timer.

Developed as an analogue of the electric wave filter, the acoustic filter provides for the attenuation of certain vibration frequencies and allows for the passage of a restricted range. Since any disturbing frequencies that might accompany the fundamental of the tuning fork would be harmonics, these undesired bands would lie outside the fundamental band and hence could be separated by filtering action. This would not be possible if the entire frequency group fell within a single band. The acoustic wave filter used in the present investigation is the simplest of the band-pass type. With the side branches open, it passes frequencies lying within the upper and lower limits of the band and attenuates all others. With the side branches closed, the filter becomes a low-pass filter—passing frequencies from zero up to a given cut-off frequency. As the limits of the frequency bands vary inversely as the square root of the volume of the chambers, the locations of the pass-bands may be shifted by varying the volume of the filter.

In addition to the attenuation of undesirable frequencies, the band-pass filter with its quick change to the low-pass type serves as a convenient device for varying the sensation level of tones. Thus, with the pass-band of frequencies set just above the fundamental of the tone presented, the fundamental frequency will be attenuated as well as its harmonics. With the same setting of the filter volume, but acting as a low-pass type, the fundamental frequency is transmitted but the harmonics are attenuated as in the band-pass filter.

Procedure

The method of right and wrong cases, or constant stimuli, was employed in every phase of the procedure. Curves, based upon data obtained for stimulus differences above and below the apparent threshold, were interpolated to give the true threshold at 75 per cent correct judgments. The number of trials varied with the observer and the several parts of the investigation. For the determination of pitch sensitivity at different loudness levels, the number of trials per observer ranged from 250 to well over 3,000. For the study of the effect of unequal loudness of the two tones, and also of the longer time intervals between the presentations of the tones, the trials were fewer.

Ordinarily the tones were presented for a duration of one second separated by an interval of one second; the pairs of stimuli were given every ten seconds for a series of twenty-five trials. The order of presentation of high and low tones was predeter-

mined by a key which allowed for an equal number of H and L and no more than two trials of the same order in succession. The observer judged the second tone of each pair to be either higher or lower than the first; where the subject was doubtful, he was required to guess. The judgments were signalled by means of a buzzer to the experimenter in an adjacent room.

Preliminary to any determination of pitch sensitivity the stimuli were equated for loudness. This was accomplished by first making the tuning forks of identical frequency; and, second, by giving a series of twenty-five trials. If the subject reported 50 percent correct judgments (chance), the stimuli were assumed to be of equal loudness. Usually the subject based his judgment upon pitch rather than upon loudness differences—the second tone always appearing higher to some observers and lower to others. Throughout the investigation, the forks were maintained at a constant intensity level, the loudness being just above the threshold when the acoustic filter was of the band-pass type. Different sensation levels were obtained by changing the action of the filter from the band-pass to the low-pass type.

Subjects

With two exceptions, the subjects were students in the elementary psychology courses. Most of them had little or no musical training; they all had, apparently, normal hearing. In addition to these students, the services of two students working under the National Youth Administration program were obtained. With these latter subjects, it was possible to obtain a large amount of data. Serving as observers daily for a period of several months, their judgments on pitch discrimination at various loudness levels totalled over 6000. One of these subjects was a highly trained musician, having a pitch limen of a quarter of a vibration per second. Limens were obtained for twelve subjects for two or more experimental conditions.

Part I. Variation of Loudness Level

In this part of the investigation, limens were determined principally at two intensity levels: supra-liminal and the full intensity of the tuning fork. In each case, the supra-liminal tones were just above the intensity threshold (this varied slightly for the several subjects), and the full intensity tones approximated in intensity level 50–60 decibels. In a given experimental session, series of 25 trials were alternated for the loud and for the weak tones. Thus, in successive test periods the sequence of presentation of the several series was varied to eliminate any conditioning effect of a given loudness level upon the one following it.

Part II. The Effect of Loudness upon Pitch

In Part I, both members of the pair of stimuli were of equal loudness; the tones were presented at a low, at a medium, and again at a relatively high loudness level. This procedure was designed to measure pitch sensitivity for various degrees of excitation of the auditory mechanism. The purpose of Part II was to show the effect upon pitch of varying the loudness of one member of the pair of stimuli while the second member was held at a constant loudness level. Thus, while the procedure of Part I attempted to measure the effect of loudness upon pitch discrimination, that of Part II attempted to measure the effect of loudness upon the attribute of pitch, *per se*.

The procedure adopted to show the effect of decrease in intensity upon pitch was as follows: Since a decrease in loudness was judged to be an increase in pitch, the lower frequency tone was always made weaker, regardless of whether it was presented

first or second. The frequency of the higher tone was then increased until it was judged to be equal in pitch to the low-weak tone. The loudness level of the variable frequency tone was held constant at 50–60 db; that of the standard frequency tone (256 dv/sec) was decreased by 15 percent.

Part III. Variation of Time Interval between the Members of Paired Stimuli

In Part I and Part II, the tones were presented for a duration of one second separated by an interval of one second; successive pairs were presented every ten seconds. For the longer time intervals between the members of a given pair, periods of ten, thirty, and sixty seconds were chosen. Corresponding intervals of ten, thirty, and sixty seconds were allowed between the presentations of successive pairs. Manual control of the sound valve in the sound-proof room provided for the audibility of either the higher or the lower frequency tone at the proper time.

Perhaps the most rigorous test of the effect of time interval upon pitch discrimination is the variation of the time interval during a given series of judgments. Thus, following the presentation of, say, a dozen pairs of one second interval tones, a group of ten second interval tones would be given; then the interval would be successively increased to the thirty second, and even a few of the sixty second interval pairs would be presented during a single series.

The subject would then be given a rest period, the air in the sound-proof room changed, and another series beginning with the longer intervals and ending with the one-second interval would be given. The observers often reported that they were not conscious of any change in the length of the time interval which exceeded ten seconds. This fact would indicate an ideal experimental condition, relative both to technique and to the attitude of the observer.

Part IV. The Effect of Loudness upon Pitch with Variation in Time Interval

The procedure here was simply a combination of that in Part II and Part III.

Results

The limens for pitch have been tabulated for each subject for the several experimental conditions. For Part I Variation of Loudness Level and Part III Variation of Time Interval, the changes in the limens as effected by a variation in the experimental condition are shown.

Part I.—All the observers agreed that the only difference in judging the tones at the different loudness levels was in the greater degree of attention required for the supra-liminal tones. In most cases, daily variation in pitch sensitivity was slight. Although the determinations extended over a period of several months, there was no evidence of practice effect.

Part II.—When the stimulus difference was small, all of the observers were perfectly confident that the louder tone was lower in pitch than the weaker tone. This was shown conclusively when the tones were equated for frequency, but

TABLE I

Subjects	Ric	Bru	Par	Cox	Ste	All	Gei	Con	Mye	Lon	Lea	Sne
PART I												
Supra-Liminal	0.28	1.45	1.60	1.64	1.55	1.42	3.80					
Full	0.25	1.50	1.65	1.55	1.45	1.50	2.90	1.50	2.10	2.00	1.15	1.55
Medium	0.28	1.65										
PART II—UNEQUAL LOUDNESS												
	1.52	10.00	2.80		3.10	1.80		4.40	2.00	3.90		
PART III												
10 Seconds	0.35	1.20	0.90		1.50	0.80		1.25	1.50	1.45	0.65	0.95
30 Seconds	0.40							1.40	1.40	1.55		
60 Seconds	0.55							1.10	2.10	1.40		
PART IV—UNEQUAL LOUDNESS												
10 Seconds	1.10							4.60	1.60	4.30		
30 Seconds	1.00							5.40	1.00	4.50		

The above values are limens for pitch discrimination expressed as that difference in frequency (dv/sec) to which the observer would respond correctly in 75 percent of his judgments (Parts I and III); and in 50 percent of his judgments (Parts II and IV).

The limens were interpolated from curves.

TABLE II

Subjects	Ric	Bru	Par	Cox	Ste	All	Gei	Con	Mye	Lon	Lea	Sne
Part I. Decrease in Loudness Level to Supra-Liminal—												
+	0.03			0.09	0.10		0.90					
−		0.05	0.05			0.08						
Part III. Increase of Time Interval to:												
10 seconds +	0.10				0.05							
−		0.25	0.75			0.70		0.25	0.60	0.55	0.50	0.60
30 seconds +	0.15											
−								0.10	0.70	0.45		
60 seconds +	0.30											
−								0.40	0.00	0.60		

The above values represent the changes in the limens (dv/sec) effected by a variation of the experimental conditions. The change is relative to the limen obtained for the given standard condition: stimuli of equal loudness (50–60 db) presented for duration of 1 second with time interval of 1 second between members of pair. An increase in the limen is indicated by (+), a decrease by (−).

one was presented as slightly louder than the other. As the difference in loudness was increased, there was a corresponding increase in the percent of judgments indicating the louder tone to be lower in pitch.

Part III.—For the comparison of the 10 second with the 1 second time interval between members of the paired stimuli, limens were determined for ten subjects; limens for the 30 and the 60 second intervals were obtained with four of these observers. In eight of the ten cases there was a decrease in the limen with an increase in the interval from 1 to 10 seconds.

The majority of observers reported that stimuli separated by an interval of 10 seconds were much easier to judge than those separated by only 1 second. Judgments for the 30 second interval were similar to those for the 10 second period. Judgments for the longer intervals were often made relative to the first member only of the pair of tones. Thus, after hearing one of the tones, the observer could predict the pitch of the second before hearing it. Usually these predictions were not changed by the appearance of the second tone. Whether the prediction actually proved to be correct or not seemed to depend only upon the magnitude of the stimulus difference.

Part IV.—When both the factors of loudness inequality and variation of time interval are present, the result is an increase in the limen for some observers and a decrease for others.

Summary of Results

1. For the frequency level of 256 cycles per second, differential pitch sensitivity remains constant for supra-liminal, medium intensity, and loud tones.

2. Daily variation in acuity is slight; there is no evidence of practice effect in pitch discrimination for ears of very acute or of average sensitivity.

3. For the loudness level of 50–60 decibels, a moderate decrease in intensity produces a relatively great increase in pitch.

4. Pitch sensitivity increases with the lengthening of the time interval between members of the stimuli pair from 1 to

10 seconds. There is a smaller increase in sensitivity for the time intervals of 30 and of 60 seconds.

5. The influence of loudness upon pitch becomes more effective for some observers and less effective for others with an increase in time interval.

Interpretation of Results

If the modernized resonance theory of hearing is accepted, then the fact that differential pitch sensitivity remains constant for supra-liminal, medium intensity, and loud tones means simply that the same nerve fibers respond to these different degrees of stimulation with equal readiness for the analysis of pitch. Assuming that the intensity of the tones is correlated with the frequency of impulses in these particular fibers, then loudness may vary while pitch sensitivity remains constant. If, however, loudness is correlated with the number of fibers activated, as required by the principles of resonance, then there should be a greater spread of neural response for loud tones than for supraliminal tones and pitch discrimination should be affected.

Wever and Bray, in an explanation of their study of action currents generated in the auditory nerve, make both frequency and intensity dependent upon the frequency of nerve impulses per unit time. While this view does not explain the mechanism for hearing, it permits both multiplicity of fibers and frequency of impulse to contribute toward the total number of impulses in the auditory nerve which is correlated with pitch and loudness. Upon the basis of the present results, it is proposed that when a given magnitude of neural response is exceeded, spatial mechanical resonance becomes inadequate as a basis for pitch discrimination and is supplemented (wholly or in part) by frequency of impulse.

The results of the second part of the investigation, the variation of pitch with loudness, offer further modifications for a 'place theory' of pitch based upon principles of resonance. In the majority of cases, there is a definite rise in pitch corresponding to a decrease in intensity of stimulation. With respect to the resonant properties of the organ of Corti, this

means a shift in response toward the basal end of the cochlea. Such a change in location would indicate that pitch is correlated with certain asymmetrical properties of the auditory mechanism which cause a variation in the pattern of response with different degrees of stimulation of the membrane-partition.

When we consider auditory experience as correlated with the total number of impulses in the auditory nerve, the variation of pitch with loudness presents evidence which is somewhat contradictory. Assuming that the total number of impulses passing along the nerve per unit time is correlated with both pitch and loudness, then a decrease in either of these factors is a decrease in the total number of impulses. But this summation of impulses appears to be something more than a simple addition or subtraction process. The decrease in stimulus intensity does not merely reduce the number of those impulses specific for intensity and hence produce a decrease in the loudness of the sensation. A secondary effect is produced upon pitch, and where the reduction in intensity is moderate this secondary effect of rise in pitch predominates over the primary effect of decrease in loudness.

If the attribute pitch were independent of the attribute loudness and remained constant irrespective of intensity changes, then it could be argued that pitch had its own set of impulses and loudness had its set and the increase or decrease in the total number of impulses caused by either of the factors would not affect the other. The interdependence of the attributes, however, raises a serious objection to the acceptance of a volley theory of pitch and intensity. Thus, while the results of the first part of the study tended to show the inadequacy of a simple resonance mechanism for frequency analysis, the change of pitch with loudness, as evidenced in the second part, seems to discredit the notion of pitch and loudness as dependent primarily upon a summation effect of nerve impulses.

That the ultimate analysis of frequency may depend upon the co-functioning of the central nervous system finds sup-

porting evidence in the results of the third and the fourth part of the study. Thus the increase in pitch sensitivity and the shift in the loudness effect upon pitch with the lengthening of the time interval may indicate that the central processes function more effectively when a sensation of pitch is allowed to "sink in" than when it is immediately followed by a dissimilar sensation.

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References

1. Rucknick, C. A., A critical review of the field of audition, *Psychol. Bull.*, 1936, **33**, 407.
2. Culler, E. A., Finch, G. and Girden, E., Functions of the round window in hearing, *Amer. J. Physiol.*, 1935, **111**, 416–425.
3. Crowe, S. J., Guild, S. R. and Polvogt, L. M., Observations on the pathology of high-tone deafness, *Bull. Johns Hosp.*, 1934–35, **54**, 315–340.
4. Stevens, S. S. and Davis, H., Psychophysiological acoustics: pitch and loudness, *J. Acoust. Soc.*, 1936, **8**, 1.
5. Davis, H., Derbyshire, H. J., Lurie, M. H., Kemp, E. H. and Upton, M., Functional and histological changes in the cochlea of the guinea pig resulting from prolonged stimulation, *J. Gen. Psych.*, 1935, **12**, 251–278.
6. Wien, Uber die Empfindlichkeit des menschlichen Ohnes für Tön verschiedener Röhe, *Pflüger's Arch.*, 1903, **97**, 1.
7. Guernsey, M., Study of liminal sound intensities, *Amer. J. Psych.*, 1922, **33**, 554.
8. Rayleigh, On the minimum audible current in the telephone, *Phil. Mag.*, 1894, **38**, 285–295.
9. Shower, E. G. and Biddulph, R., Differential pitch sensitivity, *J. Acoust. Soc.*, Oct. 1931.
10. Snow, W. B., Change of pitch with loudness at low frequencies, *J. Acoust Soc.*, 1936, **8**, 14.

RELATION OF VOLUNTARY MOTOR PRESSURE DISORGANIZATION (LURIA) TO TWO OTHER ALLEGED COMPLEX INDICATORS [1]

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Hull and Lugoff (4) measured the degree of association between alleged complex indicators and found them to have for the most part low positive relationships. More recently Luria (7) has suggested a new indicator—voluntary motor pressure disorganization. This indicator was not, of course, included in the Hull and Lugoff comparison, and the present experiment was undertaken to determine the degree of association between the Luria indicator and two others: long reaction time and failure in reproduction of the response word (Jung).

Luria used a conventional free association technique and instructed his subjects to press a pneumatic bulb held in the preferred hand at the same time they gave the response word. The non-preferred hand remained passive holding a weight to which was attached a sensitive stylus that would record involuntary tremors on a kymograph. Unusual fluctuations in the tracings of the two responses were interpreted as indicators of emotional blockages or complexes associated with the response word which accompanied the fluctuations. Luria did not attempt to correlate his findings quantitatively with findings by other complex-indicating techniques.

Hull and Lugoff found a coefficient of association of + .40 between long reaction time and three other complex indicators massed together (repetition of stimulus word, assimilation and defective reproduction), and one of + .25 between defective

[1] This paper was adapted from a thesis written in partial fulfillment of the requirements for graduation in psychology. The problem was suggested by Dr. Robert R. Sears, under whose direction this research was carried out at the Department of Psychology, University of Illinois.

reproduction and three others massed (first two above and long reaction time).

Method

Under conditions of a free association experiment measurement was made of three complex indicators: long reaction time (over 2.6 seconds), failure in reproduction of the response word, and the Luria indicator. A list of 99 stimulus words, in part chosen from Jung's (6) and Darrow's (2) lists and in part devised by the writer was prepared. No systematic word-order was used in its construction except that in some instances critical words followed certain predisposing word-types in order better to emphasize the emotional meanings of the critical word; e.g., 'woman' immediately preceded 'petting.'

Apparatus.—The S was seated before two large tambours which were spaced a sufficient distance apart to permit him to rest the first 2 or 3 fingers of each hand on them comfortably. Pressures were recorded by 2 Marey tambours on stylograph paper carried in a constant-speed polygraph. The 2 receiving tambours were capable of transposition and the same recording system was therefore always used for voluntary or involuntary responses whether the S was right- or left-handed. Reaction time was recorded by a hand key operating a magnetic marker. The key was closed by E at presentation of a stimulus word and opened at the instant of the S's response. The E and apparatus were hidden from the S by a screen.

To prevent, as far as possible, the introduction of motor pressure artifacts the S was cautioned to remove his hand from the sensitive tambour if he for any reason found it necessary to change his position. A period of rest was given whenever the S felt fatigued, since it was necessary for him to hold his left (involuntary pressure) hand unsupported on the tambour in order that the sensitivity of movements might be increased and thereby more closely approximate Luria's experimental conditions.

Instructions.—The following typewritten instructions were given to the subject to read: "Gently rest the fingers of the left hand on the left tambour and the fingers of the right hand on the right tambour throughout the course of the experiment. The experimenter will present a word out loud to which you are to respond with the very first word that comes to your mind, at the same time pressing the right tambour but holding your left hand steady. The stimulus will sometimes be a single word, sometimes two words and sometimes a sentence. In any case you are to respond to the stimulus with the first word that comes to your mind. Do not ask the E if the sentences are the stimuli. They are, and you are to respond to them. Speak distinctly when giving your responses. Focus your attention continually on the stimulus word given by the experimenter."

After E was satisfied that the S fully understood the instructions a number of examples were given to mechanize the response and establish the voluntary pressure and verbal response as a unified pattern of reaction. The importance of simultaneity in the verbal and motor response was stressed. After the free associations had been completed the S was given these instructions: "You may sit quietly and relax. It will not be necessary for you to press or touch anything. I am going through the list of words again and I want you to respond with the same word that you responded with before. You may take as long a time as you wish to remember and if you remember or think you remember say the word, while if you know definitely that you don't remember, just say 'I can't remember.'"

In order to avoid consciously controlled or 'extra-signalizing' (environmentally controlled) responses, the experimental procedure was carried through as rapidly as

the responses could be recorded, and no attempt was made to record other possible complex indicators such as laughing and peculiar movements.

Measurement of Luria Indicator.—In a preliminary study with Jung's list, 40 S's were tested for reaction time, reproduction and the Luria indicator. Sample measurements showed a purely chance relationship between two objective measures of the voluntary Luria response, intensity and duration (height and breadth of curve), and the other two complex indicators, although Luria states that he took account of the intensity of pressure in his judgments. A careful examination of individual pressure responses to words which had obviously produced emotional disturbance led to the conclusion that the form of the motor curve disruption is more or less of an individual phenomenon, being dependent on the type of reactor, whether reactive stable or reactive labile,[2] on the type of verbal response accompanying the pressure (*i.e.*, whether stereotypy, repetition of the stimulus word, extra-signalizing, etc.) and other factors. Thus a certain type of break-down on the structure of the 'motor-formula' which constitutes an externalization of inner disruption of the psychological processes for one person may be normal to another. It seemed desirable, therefore, to evaluate discoordination of the motor record in terms of an assumed normal reaction for each subject. With reactive stable subjects no difficulty was encountered since gross fluctuations were brought out in relief by the very fact of their distinct difference from the normal. These subjects probably correspond to Burtt's Type 5 and Type 19 (1).

The responses of reactive-labile subjects were more difficult to evaluate since their normal response was, by definition, a highly variable affair. During the scoring of the Luria indicator the reaction-time line was, of course, always covered in order not to prejudice the judgments toward a positive correlation with long reaction time.

Justification for judging normality in terms of the structure of the response-as-a-whole rather than in terms of a specific objective measure comes from two sources: first, the evident failure of intensity or duration to discriminate what Luria means by a disorganized response;[3] and second, Luria's theory of the voluntary motor response. His view is that the method involves the association of higher central nervous system processes with a voluntary movement so that conflicts in the former are disclosed in the latter. "Having trained a subject to associate a motor response of the preferred hand with every verbal response, thereby establishing a close functional relationship between them, any word occurring to the subject which he does not give as a response will appear in the voluntary movement as a partial reaction" (Luria). It is assumed that the inhibition of the verbal response is associated with affect; *i.e.*, the subject does not respond with the first word since some complex would be revealed. Also the pressure curve may lose its smooth, regular character; "the normal voluntary movement is discoördinated or disorganized because stimuli which elicit responses possessing affect may also arouse larger amounts of excitation than stimuli eliciting nonaffective

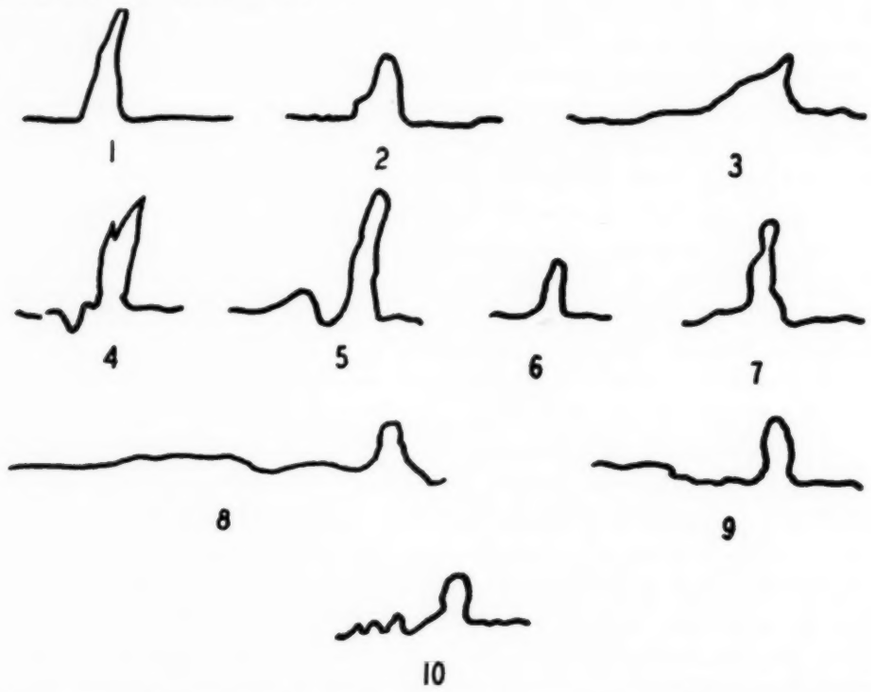
[2] Luria uses these terms to designate respectively the composed stoical type of reactor and the nervous flighty type. Burtt (1) has presented graphic evidence that subjects differ markedly in the general form of their motor responses, and Gardner (3) has shown that certain irregularities in the reaction pattern are highly consistent within any one subject. For example, he found a correlation of $+ .83 \pm .04$ between amount of deflection in the latent period for critical words and amount for neutral words.

[3] All measurements had been made and this paper prepared for publication before Gardner's study appeared. Gardner (3) found two valid quantitative measures of the voluntary Luria response: amount of disturbance during latent period, amount of perseverative pressure following the reaction.

responses." The excitation tends to discharge itself immediately via the voluntary motor pathway. Luria has referred to this tendency as the law of the catalytic action of the stimulus.

According to Luria the expressiveness of any motor system will depend upon its degree of inclusion in the psychological structure in which the conflict is located; hence the preferred hand is selected to make the voluntary pressure because of the close relationship between the speech centers and the neural control of the preferred hand.

In Figs. 1–10 are given examples of both normal and disorganized motor responses from the group of 40 preliminary S's.



FIGS. 1–10. Structure of 10 motor pressure responses. The context of each is indicated below with use of the following abbreviations. Subject type: RS = reactive stable; RL = reactive labile. Reaction time: (+) = greater than 2.6 seconds; (−) = less than 2.6 seconds. Reproduction: (−) = same as original response; (+) = failure to recall. Luria: (+) = disorganized; (−) = normal.

Fig.	Stimulus Word	Subject Type	Response	R.T.	Reprod.	Luria
1	despise	RS	hate	−	−	−
2	box	RS	put something on	+	−	+
3	suck	RL	draw upon	+	−	+
4	wicked	RL	wrong	−	−	+
5	try	RL	do	+	−	+
6	queer	RS	people	−	−	−
7	operation	RS	process	−	−	+
8	sexual	RL	male	+	−	+
9	popularity	RL	indifferent	+	+	+
10	hot	RL	cold	−	−	+

With the Jung word list relatively few Luria indicators occurred. In order to increase the total number, for reasons of statistical reliability, in the experimental group, the list given in Table 1 was used. Because of its relatively infrequent occur-

TABLE 1

THE 99 WORDS USED FOR FREE ASSOCIATION TOGETHER WITH THE FOLLOWING INFORMATION IN SUCCEEDING COLUMNS

1. Frequency of occurrence of the Luria indicator in 30 cases.
2. Frequency of occurrence of long reaction time in 30 cases.
3. Frequency of occurrence of failure at reproduction in 30 cases.
4. Frequency of occurrence of all three indicators in 17 men (maximum = 51).
5. Frequency of occurrence of all three indicators in 13 women (maximum = 39).
6. Frequency of occurrence of all three indicators in 30 cases (men and women; maximum = 90). The 14 most critical words are indicated by a dagger (†) and the 10 least by an asterisk (*).

Stimulus Word	1	2	3	4	5	6
Green	3	2	6	10	1	11
Water	3	0	8	8	3	11
Ship	1	2	1	3	1	4*
Guts	4	8	1	5	8	13
Queer	3	5	6	12	2	14
Friendly	2	3	12	10	7	17
Cold	4	4	10	7	11	18
Nasty	5	1	5	4	7	11
Fruit	1	1	3	3	2	5*
Blue	3	1	5	5	4	9*
Bread	3	2	7	6	6	12
Rich	2	0	6	7	1	8*
Physic	8	12	3	13	10	23
Tree	6	3	4	9	4	13
Insult	6	15	11	26	6	32†
Virgin	6	9	4	13	6	19
Evil	2	1	7	5	5	10
Salt	4	7	4	10	5	15
New	3	4	3	6	4	10
Divorce	6	3	8	10	7	17
Carry	7	6	7	11	9	20
Pride	10	13	12	22	13	35†
Swim	7	3	5	7	8	15
Trouble	6	10	13	14	15	29
Sick	11	8	11	21	9	30†
Make	7	9	6	16	6	22
Caress	4	4	8	10	6	16
Passion	9	12	13	25	9	34†
Money	4	8	7	12	7	19
Man	6	2	5	7	6	13
Fairy	8	10	4	14	8	22
Speak	5	3	5	9	4	13
Try	7	7	13	17	10	27
Woman	5	5	6	10	6	16
Petting	5	13	12	16	14	30†
Home	7	10	11	14	14	28
Family	5	7	4	9	7	16
Sad	10	9	18	21	16	37†
Adolescent	4	10	2	7	9	10
Brother	4	4	2	7	3	10
Habit	8	12	6	13	13	26
Carrot	10	4	0	8	6	14
Chair	4	3	5	6	6	12
Sweetheart	7	6	5	13	5	18

TABLE 1—*Continued*

Stimulus Word	1	2	3	4	5	6
Pregnant	9	8	4	14	7	21
Marriage	8	9	13	19	11	30†
Box	5	8	3	5	11	16
Suck	8	15	2	14	11	25
Neck	5	13	7	15	10	25
Child	8	5	10	12	11	23
Dance	10	8	6	15	9	24
Coarse	7	10	5	13	9	22
Afraid	5	7	9	11	10	21
Self	7	13	7	17	10	27
Abuse	7	6	12	13	12	25
Despise	3	3	4	8	2	10
Wicked	3	4	9	8	8	16
Operation	8	3	2	8	5	13
Door	2	1	3	2	4	6*
Pleased	10	10	16	23	13	36†
Happy	2	9	13	14	10	24
Purity	8	13	5	15	11	26
Rubber	5	9	3	8	9	17
Sexual	8	15	7	15	15	30†
Table	1	4	4	8	1	9*
Paper	1	4	1	4	2	6*
Frog	6	3	2	4	7	11
Weakness	7	15	8	20	10	30†
Inferiority complex	6	12	10	16	12	28
Popularity	6	11	5	15	7	22
Wall	4	5	4	6	7	13
Rotten	6	7	5	14	4	18
Wish you were a success	5	12	4	15	6	21
Walk	3	2	3	3	5	8*
Bird	1	2	2	4	1	5*
Wicked	3	7	15	15	10	25
Infection	6	10	3	6	13	19
Girl	3	7	8	9	9	18
Bloody	2	11	3	9	7	16
To sin	4	12	10	15	11	26
Bed	2	8	6	6	10	16
Frosty	7	2	1	4	6	10
Embarrassed	8	16	8	20	12	32†
Jolly	4	4	8	11	5	16
Contemplate suicide	8	12	5	18	7	25
Hot	3	4	1	3	5	8*
Separate	4	4	4	7	5	12
Kiss	8	10	12	19	11	30†
Faithless	8	13	12	17	16	33†
Jump	5	4	4	9	4	13
Pray	4	9	2	11	4	15
Hunger	5	6	4	9	6	15
Wound	5	8	5	12	6	18
Music	2	7	4	8	5	13
Clean	4	3	6	8	5	13
Worry	9	11	11	17	14	31†
Luck	6	9	9	14	10	24
Afraid I'll find out something	8	8	2	12	6	18
Button	4	9	2	10	5	15

rence even with the increased potency of the second group of stimulus words, involuntary fluctuations were considered as reinforcements to our choice when present with voluntary disruption rather than as a separate variable in itself. Luria's weight-holding apparatus for the involuntary reaction was much more sensitive than ours and therefore could very easily account for discrepancies in the frequency of occurrence of the involuntary fluctuation.

Subjects.—The results from the preliminary group of 40 S's were used for developing the conception of motor pressure disorganization. All results presented below were obtained from a later group of 17 men and 13 women students who served voluntarily as subjects.

Results

1. *Relationships Between Three Complex Indicators*

In Table 2 are given the inter-associations between the three indicators in terms of Yule's coefficient of association (Q), which is considered roughly equivalent to Pearson's *r*. These values are the averages of the 3 Q's obtained for each of the 30 subjects. In columns 2 and 3 of Table 2 are given the range and S.D. of these 3 distributions of 30 Q's each.

TABLE 2

Mean, Range, and S.D. of 3 Distributions of Coefficients of Association (Q) between Complex Indicators ($N = 30$)

Indicators Associated	Mean	S.D.	Range
Reaction time and Luria	+.65	.25	−.11–+.97
Reaction time and reproduction	+.39	.23	−.16–+.83
Luria and reproduction	+.24	.23	−.25–+.60

2. *Comparative Potency of Stimulus Words*

Stimulus words which initiate emotional responses are, of course, peculiar to each individual. Luria used for his investigation words which were known to be intimately linked with the affective life of his subjects. Some of these were criminals awaiting trial; others were students awaiting the 'purge' examinations. In all cases he was dealing with *known* sore spots in the affective life. The present experiment has been conducted with words which were only *assumed*, from a knowledge of contemporary social taboos and customs, to be associated with complexes. It is not surprising then that the present list aroused fewer complex indicators than did Luria's list.

In Table 1 are shown the relative potency of various words for calling up complexes when different indicators are used as criteria. The only notable sex difference not indicated by the values in columns 4 and 5 of Table 1 is a 7 percent greater failure at reproduction in the men.

Discussion

Since Gardner (3) has shown the possibility of obtaining an objective measure of the Luria indicator, its usefulness for research purposes must be considered greatly enhanced. Forced dependence on such qualitative measures as have been used in the present study would raise serious doubts as to its usefulness. With reactive stable S's there is little difficulty in judging its presence but the reliability (or validity) of judgment with reactive labile S's must necessarily be low. The positive correlations with long reaction time and failure at reproduction indicate a slight relationship and, if the argument of Hull and Lugoff is followed, a definite validity for the Luria indicator.

The same may be said, though with less certainty, regarding the validity of failure at reproduction as a complex indicator. Whately Smith (9) considered it the best indicator available but certain theoretical considerations, as well as the low correlations with other indicators, raise serious doubts as to its usefulness. An occasional *evasion* in a response may produce long reaction time but, because of vividness of association, no failure at reproduction. All emotionally toned responses are not susceptible to repression, as Sears (8) has emphasized, and thus may produce long reaction time, motor disorganization, laughing, etc. without a failure at reproduction. When the reproduction test is given immediately after the free associations, as in the present experiment, any repression must operate at once and must clearly be of the after-expulsion type (8). Forgetting as a result of non-affective retroactive inhibition must also be taken into account. These various alternative sources of failure at reproduction lower the usefulness of the indicator as a clinical tool to a serious degree. From a research standpoint it may

be considered as valid, but of such low reliability *qua* indicator that only with large groups, and with questions to which only a rough statistical answer is desired, is its use justified.

Conclusions

1. Voluntary motor pressure disorganization (Luria) is a valid complex indicator if long reaction time and failure at reproduction are used as criteria.

2. Coefficients of association (Q) between the three indicators are small but clearly positive.

3. Judgments of motor disorganization are much more reliable with the responses of reactive stable subjects than with those of reactive labile subjects; the Luria indicator is probably of little value with the latter group.

4. The only sex difference of probable significance was a 7 percent greater failure at reproduction in the men.

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References

1. Burtt, H. E., Motor concomitants of the association reaction, *J. Exper. Psychol.*, 1936, **19**, 51–63.
2. Darrow, C. W., Electrical and circulatory responses to brief sensory and ideational stimuli, *J. Exper. Psychol.*, 1929, **12**, 267–300.
3. Gardner, J. W., An experimental study of the Luria technique for detecting mental conflict, *J. Exper. Psychol.*, 1937, **20**, 495–506.
4. Hull, C. L., and Lugoff, L. S., Complex signs in diagnostic free association, *J. Exper. Psychol.*, 1921, **4**, 111–136.
5. Huston, P. E., Shakow, D., and Erickson, M. H., A study of hypnotically induced complexes by means of the Luria technique, *J. Gen. Psychol.*, 1934, **11**, 65.
6. Jung, C. G., The association method, *Amer. J. Psychol.*, 1910, **21**, 219–269.
7. Luria, A. R., *The nature of human conflicts.* (Trans. by W. H. Gantt.) New York: Liveright, 1932.
8. Sears, R. R., Functional abnormalities of memory with special reference to amnesia, *Psychol. Bull.*, 1936, **33**, 229–274.
9. Smith, W. W., *The measurement of emotion.* New York: Harcourt, Brace and Company, 1922.

THE EFFECT OF SHOCK AT THE 'MOMENT OF CHOICE' ON THE FORMATION OF A VISUAL DISCRIMINATION HABIT

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A series of studies on the effect of a systematic variation of the factor of electric shock in the learning of a discrimination habit has been carried out by Muenzinger. The results of the experiments, as well as most previous experimentation in the field, have indicated in every case that shock after the choice-point leads to more efficient learning than does the presence of hunger-food tension alone; that this influence is not significantly less when correct responses are so shocked rather than wrong responses (**4**); that when both right *and* wrong responses are shocked immediately after choice there is not a summation of effect, but an increase in efficiency no greater than that produced by shocking either type of response alone (**5**); that shock *before* the choice point decreases the efficiency of learning, and that this retardation seems to be due to the prevalence of position habits in the shock-before-choice groups (**1**, **3**, **5**); and that when the animal is shocked throughout the entire run of a discrimination (except in the 'goal box,' thus producing what Muenzinger terms 'shock-escape tension') the efficiency of learning is slightly less than if there is shock only immediately after choice (**6**). This last result, Muenzinger suggests, is due to the fact that the enhancing factor of shock after choice is partially counteracted by the retarding factor of shock before choice.

The present experiment seeks further to analyze the effects of shock by introducing shock as nearly as possible at the 'moment of choice.' Shock was applied in this manner during the learning of a simple black-white discrimination by two groups of rats. The rats of the shock-wrong group were shocked at the moment they seemed about to enter the dark alley, the rats of the shock-right group at the moment they

seemed about to enter the light (food) alley. Both groups received a nibble of food at the end of each run.

Apparatus and Procedure

A black-white discrimination box comprised of a single T-unit was used. It was as nearly as possible identical with that used and described by Muenzinger throughout his series of experiments on rats (4). Electric grids were so placed that all four feet of the animal rested on them directly at the choice-point. Similar grids, which, however, were never charged, extended up the remainder of the starting alley, including the starting box. As a result the animals at no time showed any apparent wariness of the grids as such. The shock, a current of .15 ma., supplied through a vacuum tube circuit identical with that described by Muenzinger and Walz (8), was controlled by a push-button switch.

Two groups of albino rats, 5–7 weeks old, were used. The groups consisted of 20 rats each and were equated as to distribution of sexes and ages. Both groups were trained in a black-white discrimination (white positive) with food (dog biscuits) as the primary incentive. Shock was administered as nearly as possible at the choice-point when the heads of the rats were pointed toward either the dark alley (shock-wrong-group) or the light alley (shock-right-group). The current was maintained for approximately one-half second. Shock was administered only on the *first* approach to the choice-point (never more than one shock in the course of a given run).

Of the 4,000 runs comprising the experiment, 1,925 *should* have received shock, *i.e.* the rat made or began to make the response which, for his group, was to be shocked. Actually shock was administered in 1,686 of these runs. In the remaining runs, because of the speed or abruptness of the rat's movement, no shock was received by the animal. Of the shocks applied, a total of 323 caused the rat to withdraw temporarily to the center alley or (in 44 cases) to go directly down the other choice alley. In the case of the remaining 1,363 shocks the rat continued in the same direction he was pointing, often because he was moving around the corner too quickly for the shock to alter his direction. The two experimental groups show no significant differences with respect to withdrawals due to shock.

Only one error was recorded for any one trial. The criterion of entrance into a choice alley was the placing of all four feet beyond the grids. The 'light' alley was varied in the series RLLRRLRLLR. On each run, the rat remained in the starting box for 20 seconds before the door was opened, and in the food box until he had started nibbling the food. A hunger period of approximately 21 hours was used. On two nights previous to regular training each rat was allowed to remain in the maze (without shock or lights) until he had found food in both food boxes. On the first four nights of regular training, 5 runs were made by each rat, and thereafter 10 runs a night until a total of 100 runs, unless a criterion of two successive nights of 10 runs without error was reached previously. For each run a record was kept of 1, entrances into each part of the maze, 2, the presence or absence of shock and the direction of movement resulting from shock if present, 3, behavior at the choice-point with regard to pausing and looking from one alley to the other (this record was kept only for the last 15 animals of each group), and, 4, the total time to complete the run.

Results

1. Learning, in both groups, was markedly retarded by electric shock as here employed. This fact is revealed by a

criterion either of errors or of trials to learn, as compared to previous discrimination experiments by Muenzinger, the conditions of which have here been as nearly as possible duplicated.

The error scores for the two groups are given in Tables 1 and 2 and are plotted as group learning curves in Fig. 1.

TABLE 1

ERRORS OF SHOCK-WRONG GROUP

Number Sex	1 F	3 F	5 F	7 F	9 M	11 M	13 M	15 M	17 M	19 M	21 M	23 M	25 M	27 M	29 M	31 F	33 F	35 F	37 F	39 F	Total
Trials																					
0–10	3	5	3	1	2	3	5	4	4	9	5	4	4	7	3	5	7	6	5	7	
10–20	4	2	5	5	1	5	4	4	6	1	5	7	3	5	7	5	6	6	3	6	
20–30	5	5	7	5	8	5	2	5	3	4	5	3	7	5	5	4	5	7	2	2	
30–40	5	3	6	7	2	5	0	3	7	3	5	5	4	6	6	3	6	5	4	5	
40–50	5	1	3	4	7	5	0	1	5	3	5	4	5	4	5	4	2	5	1	4	
50–60	4	1	5	0	2	5		2	6	5	5	3	5	5	5	5	7	5	0	4	
60–70	4	2	1	0	2	5		3	5	5	5	1	5	5	5	5	2	5	5	2	
70–80	1	1	2		2	5		2	5	5	5	1	5	3	5	5	3	5	4	4	
80–90	3	1	2		0	5		6	5	5	5	1	5	3	5	5	6	5	1	2	
90–100	3	0	0		0	5		4	5	5	5	2	5	1	5	5	3	5	2	0	
Totals	37	21	34	22	26	48	11	34	51	45	50	31	48	44	51	46	47	54	28	36	764

TABLE 2

ERRORS OF SHOCK-RIGHT GROUP

Number Sex	2 F	4 F	6 M	8 F	10 M	12 M	14 M	16 M	18 M	20 M	22 M	24 M	26 M	28 M	30 M	32 F	34 F	36 F	38 F	40 F	Total
Trials																					
0–10	7	6	5	7	4	8	7	6	5	6	6	4	7	6	6	6	5	6	5	7	
10–20	4	6	5	5	7	5	8	6	5	5	3	4	3	5	5	5	5	5	4	9	
20–30	5	6	5	9	6	5	4	6	6	5	6	3	6	5	7	5	5	5	5	8	
30–40	5	5	5	4	5	5	5	4	4	5	3	3	9	6	5	5	5	5	5	8	
40–50	4	5	5	5	5	5	5	4	4	5	5	5	8	6	5	5	5	5	5	7	
50–60	5	5	5	5	2	5	5	2	5	5	5	5	5	5	5	5	3	5	5	4	
60–70	5	5	5	5	5	5	5	2	6	5	5	5	5	5	5	5	5	5	5	6	
70–80	5	5	5	5	5	5	5	2	5	5	5	5	6	5	5	5	5	5	5	7	
80–90	5	5	5	5	4	5	5	3	5	5	5	5	6	5	5	5	5	5	5	3	
90–100	5	5	5	5	5	5	5	5	5	5	5	5	6	5	5	5	5	5	5	3	
Totals	50	53	50	55	48	53	54	40	50	51	48	44	61	53	53	51	48	51	49	62	1024

From the tables it is seen that in the shock-wrong group only 3 of the 20 animals reached the criterion within 100 runs (3 others had an errorless series of 10 runs from 90–100). And in this group there was an average of 38.2 errors per animal.

In the shock-right group no animal reached the criterion during the experiment and the average number of errors per animal was 50.2.

These results may be compared with the *least* efficient shock situation reported by Muenzinger, that of his shock-before-choice group (**6**). Here 13 of 25 animals reached the criterion within 100 trials. The average number of errors per animal was 35.0.

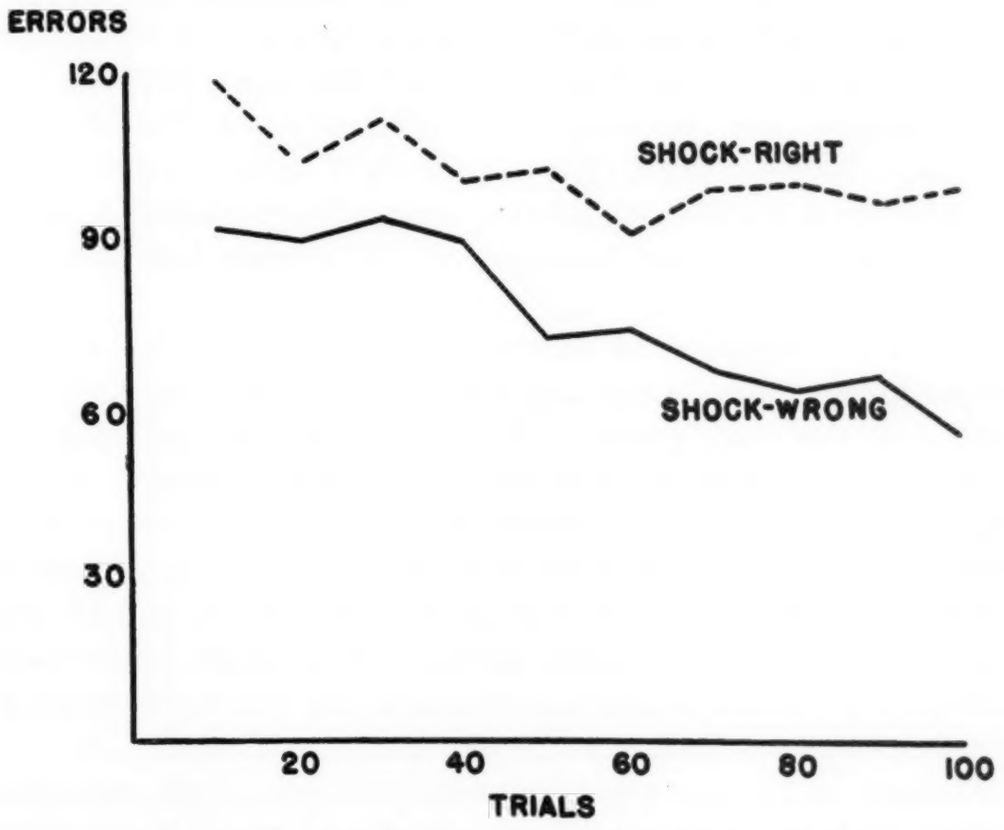

FIG. 1. Total number of errors on each series of ten trials.

Thus even the better group in the present experiment is less efficient, particularly by the first criterion, than the worst group in Muenzinger's series of experiments.[1]

2. A study of Fig. 1 shows that the shock-right group was more retarded in learning the discrimination than was the shock-wrong group. The critical ratio of the difference

[1] This comparison is limited, of course by the fact that different strains of animals and different experimenters were involved in the experiments. However, another experiment (not published) in the Princeton Laboratory, in which one of Muenzinger's procedures was duplicated, shows close agreement with his results.

between the two groups for runs 90–100 is 4.5. And in the shock-right group, as mentioned above, not one animal reached the criterion and the average number of errors per animal was 50.2. In the shock-wrong group, 3 animals reached the criterion and the average number of errors per animal was 38.2. No significant difference between the two groups was shown by the criterion of time.

3. The differences between the groups cannot be explained in terms of the number of shocks administered nor by the movements of the animals following the shocks. A tabulation of these factors showed no significant difference between the two groups nor between more-efficient and less-efficient learners individually. The shock-right group received a greater total number of shocks, as would be expected, since with them the shocked response did not become less frequent as training progressed.

4. The formation of position habits seems to be an important factor in accounting for the difference in efficiency between the two groups. The errors following complete fixation of a position habit are indicated in Tables 1 and 2 by the figures in italics. In the shock-wrong group 8 animals developed completely fixated position habits. The remaining 12 all showed varying degrees of learning at the end of 100 runs. In the shock-right group 18 animals developed completely fixated position habits; and the other two made a total error score which was far worse than 'chance.'

There is no apparent relation between these position habits and the number of shocks received by an animal prior to the complete fixation of the habits or the manner of his responses to the shocks. These observations are, however, of questionable significance. Since the formation of a position habit was a gradual process, and since the moment at which the habit began to be formed was indeterminate, it is impossible to obtain a significant measure of the effect of shocks just preceding and accompanying the formation of the position habit.

5. A further difference between the two groups is found in their behavior at the choice-point. This behavior was re-

corded as being of one of four types, 'no pause,' 'look 1' (paused, but head was turned in one direction only), 'look 2' (looked one way, then turned and went the other), and 'look 3' (looked back and forth three or more times). These records were kept for the last 15 animals in each group. The results are summarized in Table 3.

TABLE 3

TABULATION OF PAUSE BEHAVIOR

	Total number	% of these runs which were errors
SHOCK-WRONG GROUP		
no pause runs	655	54.8
look 1 runs	215	41.3
look 2 runs	263	22.4
look 3 runs	208	28.3
SHOCK-RIGHT GROUP		
no pause runs	555	49.3
look 1 runs	414	51.6
look 2 runs	215	56.2
look 3 runs	210	51.9

For each of the two groups there was nearly the same number of 'look 2' and 'look 3' runs; but the shock-right group showed many *more* 'look 1' runs and *fewer* 'no pause' runs. An important element in this difference between the two groups is the fact that in the shock-wrong group 88.6 percent of all runs after complete fixation of a position habit showed no pause at the choice point, while in the shock-right group this was true of only 56.9 percent of such runs.

The relation of these several types of runs to errors is shown in the second column of Table 3 and indicates another difference between the two groups. In the shock-wrong group the 'look 2' and 'look 3' runs were far more efficient than the 'look 1' and 'no pause' runs, a fact which is further expressed by a rank order correlation of .85 between errors and number of 'no pause' runs in this group. In the shock-right group, however, the 'look 2' and 'look 3' runs were no more efficient than the 'no pause' runs, and a rank order correlation of $-.24$ is found between errors and number of 'no pause' runs. This latter figure is not considered significant because the prevalence of position habits prevented any clear differentiation within the shock-right group; but the difference

between this group and the shock-wrong group with respect to the relative efficiency of 'look 2' and 'look 3' runs as compared with 'no pause' runs is clearly shown in Table 3.

Discussion

The results of the present experiment are most strikingly presented by the diagram in Fig. 2. Electric shock in the position *Y*, after choice, increases learning efficiency; but shock in the position *X*, at the 'moment of choice,' retards learning.

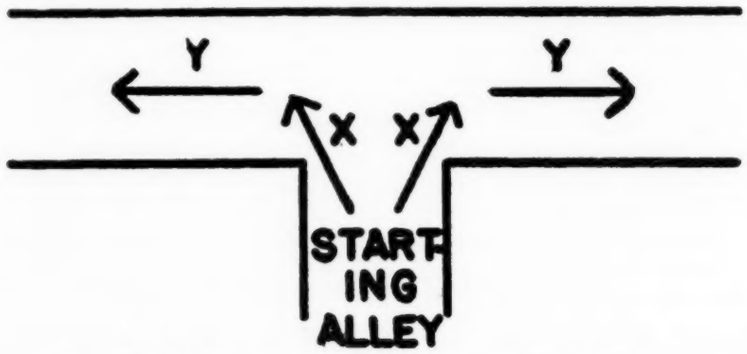

Fig. 2. Shock at the position *Y* facilitates learning. Shock at the position *X* retards learning.

Muenzinger has carried out an experiment in which an enforced pause at the choice-point, effected by means of glass doors, increased the efficiency of learning in the same degree as did shock-after-choice (7). On the basis of these results he suggests that the influence of shock on learning in the discrimination box depends on its efficacy in fostering or inhibiting pause behavior at the choice-point. From the present experiment it appears that the situation cannot be interpreted so simply; for in the case of the shock-right group pausing at the choice-point was not accompanied by any lessening of errors. Position habits seem to be a factor equally as important as and interrelated with pause behavior in this experiment.

Nor does the present experiment seem to support a conditioned reflex theory of learning such as that held by Guthrie, which states that the animal will learn to do what an electric shock, or other stimulus, makes him do in response to a given situation (2). The great majority of shocks here administered caused the animal to run more vigorously in the same direction

he was then going (namely, up the dark alley for the shock-wrong group and up the light alley for the shock-right group). Yet we have seen that these were by no means the responses that the animals of the two groups learned to make to the situation. It must be remembered, however, that there was no way of telling to what factor in the total stimulus situation the rat was responding at a given moment, be it spatial relations, the light, or some purely incidental stimulus.

There does not seem to be, at present, any hypothesis as to the nature of learning which suggests or includes the results of this experiment. Nor do the results themselves suggest any extension of theory by which they might be explained.

Summary

Two groups of albino rats, shock-right and shock-wrong groups, were trained in a black-white discrimination, shock being administered at the 'moment of choice.'

Learning in both groups was retarded.

This retardation was significantly greater in the shock-right group.

The far greater prevalence of position habits in the shock-right group seems to be an important factor in creating this difference.

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References

1. Everall, E. E., Perseveration in the rat, *J. Comp. Psychol.*, 1935, **19**, 343–369.
2. Guthrie, E. R., Reward and punishment, *Psychol. Rev.*, 1934, **41**, 450–460.
3. Hamilton, J. A., and Krechevsky, I., Studies in the effect of shock upon behavior plasticity in the rat, *J. Comp. Psychol.*, 1933, **16**, 237–253.
4. Muenzinger, K. F., I. Electric shock for correct responses in the visual discrimination habit, *J. Comp. Psychol.*, 1934, **17**, 267–277.
5. Muenzinger, K. F., and Wood, I., IV. The function of punishment as determined by its temporal relation to the act of choice in the visual discrimination habit, *J. Comp. Psychol.*, 1935, **20**, 95–106.
6. Muenzinger, K. F., and Fletcher, F. M., VI. Escape from electric shock compared with hunger-food tension in the visual discrimination habit, *J. Comp. Psychol.*, 1936, **22**, 79–91.
7. Muenzinger, K. F., and Fletcher, F. M., VII. The effect of an enforced delay at the point of choice in the visual discrimination habit, *J. Comp. Psychol.*, 1937, **23**, 383–392.
8. Muenzinger, K. F., and Walz, F. C., An examination of electrical-current-stabilizing devices for psychological experiments, *J. General Psychol.*, 1934, **10**, 477–482.

STUDIES IN THERMAL SENSITIVITY: 1. ADAPTATION WITH A SERIES OF SMALL CIRCULAR STIMULATORS

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In an earlier article,[1] it was shown that complete adaptation to a temperature of 10° C. occurred in a few seconds, with a stimulator 1¼ mm in diameter, surrounded by a field disc maintained at skin neutral. This result, obtained with six subjects, was so totally different from the slow and often incomplete adaptation usually reported with large areas, that further systematic study of small areas seemed justified. In the present investigation, the same technique has been extended to include a series of circular stimulators from 1¼ to 10 mm in diameter, using temperatures of 10° and 44° C.

Apparatus and Procedure

Fundamentally, the apparatus was the same as that used in the earlier study.[2] Its essential features are: (1) a stimulator maintained by circulating water at 10° or 44° C., and moved down against the skin by a cam; (2) a surrounding field disc thermostatically maintained by circulating water at skin neutral; (3) an adaptation timer; (4) a chronoscope.

In making each determination, the following procedure was carried out: The neutral field was lowered against the volar surface of the subject's left forearm, which was supported in a plaster half-cast. At the sound of a warning buzzer, the subject depressed the reaction key. Two seconds later, the cam turned and stimulation occurred. As soon as he felt either cold or warm, the subject released the key and immediately reported the intensity of sensation. (In the absence of thermal experience, the subject did not react.) The interval between stimulation and key release was measured by the chronoscope, giving the thermal reaction time. Release of the key also started the adaptation timer which the subject stopped (by touching another key) when the sensation had died out completely, giving the adaptation time. If complete adaptation did not occur within 120 seconds, the stimulator was removed and the subject reported the intensity of the residual sensation.

All measurements were made on the volar surface of the left forearm between

[1] Jenkins, W. L., Adaptation in isolated cold spots, *Amer. J. Psychol.*, 1937, 49, 11.

[2] *Op. cit.*, 3–5.

wrist and elbow. Stimulation of the same cutaneous area was not repeated in the same series, but the possibility of residual adaptation effects from previous runs was not excluded. The usual working period was two hours, during which approximately six series could be run, using different sizes of stimulators. Each series, depending upon conditions, consisted of five to twenty individual determinations, with an average of about 10.

The four male student subjects were given about six weeks of preliminary training in temperature discrimination. The actual data were then taken during December, 1936, and January and February 1937. Room temperature was controlled only by manual operation of a steam radiator. Relative humidity and the previous exposure of the subjects were not controlled.

Results

The principal data are shown separately for each subject in Figs. 1–4. The ordinates on the main charts are median adaptation times in seconds and those for the sub-charts are plainly marked. The abscissae throughout are the identifying numbers of the stimulators. These correspond to the diameters in mm, except that the No. 1 stimulator was actually 1¼ mm in diameter. Since the general level of adaptation time changed in the third month with 44° C. stimulation for subjects Sc, Al and De, medians for Dec.-Jan. and for Feb. are shown separately in these charts. Otherwise, there appeared to be no general shift in level and the charts show medians for the three months period. Typically, each large black dot represents the median of at least 25 individual determinations divided into at least three separate series. The small dots show the medians of the individual series and give some measure of the variability from period to period.

Since the principal interest lies in the individual differences among the four subjects, the common points may be dismissed briefly. In all charts, the length of adaptation time increases with the size of the stimulator and (very roughly) in relation to the diameter rather than to the area. There are no marked common differences in the general levels of adaptation time for warmth as compared with those for cold, but percentage of response to cold is uniformly higher for all subjects. The one minor exception is the 1¼ mm stimulator for subject Sc (Fig. 1), where the percentage of response to 44° C. (50 percent) is apparently significantly greater than

that for 10° C. (9 percent). This situation is reversed with the larger sizes.[3]

We may now proceed to an analysis of the individual differences among the four subjects:

Subject Sc (Fig. 1).—In this subject, the general level of adaptation time and the percentage of response (right-hand sub-charts) are both high. Roughly the length of adaptation

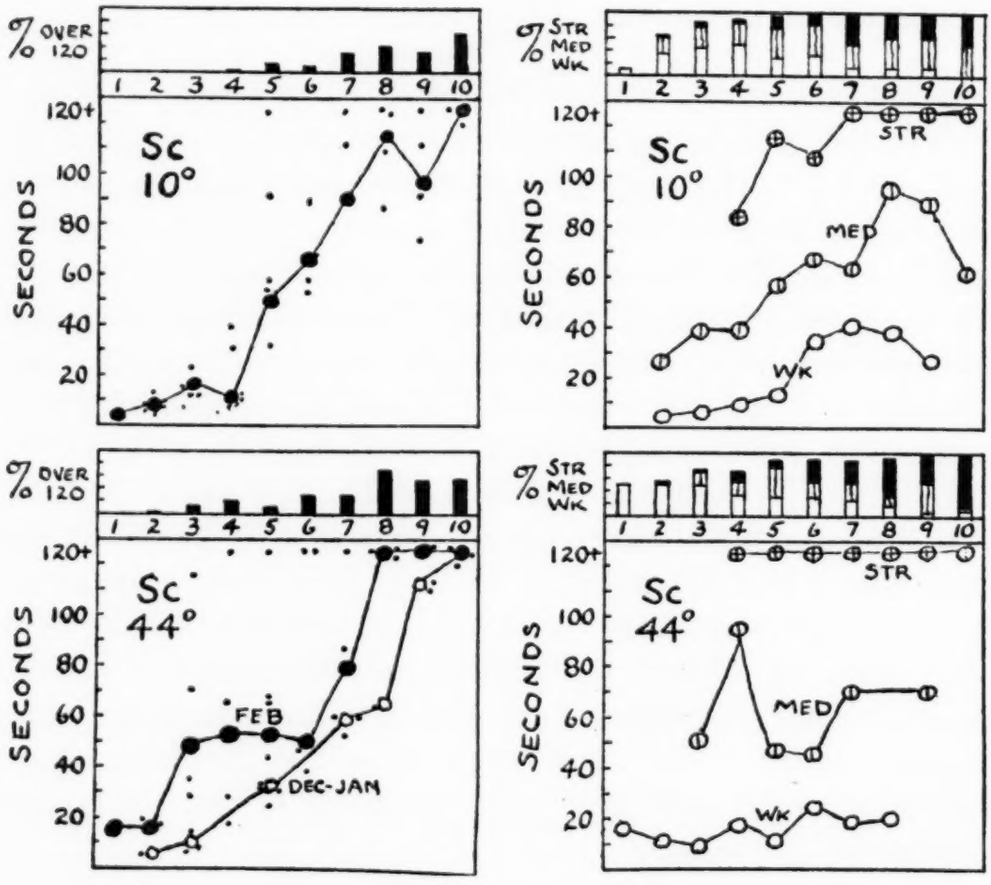


FIG. 1.

time increases with the diameter of the stimulator, but both curves are much too irregular to term either a linear relation. (Since Nos. 8, 9 and 10 in Sc-44° all show medians of 120 +, rough extrapolation may be made from the percentage of individual determinations running over 120 seconds, shown in the left-hand sub-charts.)

[3] Since the traditional mapping experiment is frequently performed with a 1 mm diam. stimulator, subject Sc might show more 'warm spots' than 'cold spots' under these circumstances, although clearly his *general* level of cold sensitivity is higher.

In the right-hand main charts are shown the median adaptation times for strong, medium and weak initial reports of sensation.[4] In both right-hand charts, there is clear separation of the three curves, probably clearer in the case of Sc-44°. An examination of the individual determinations (which space does not permit showing here) confirms the evidence of the median curves. With any given size of stimulator, there is almost no overlapping, especially with 44°. Arranged in descending order of length, all of the 'strong' adaptation times come first, then all of the 'medium' and finally all of the 'weak,' almost without exception. In spite of very wide variability from period to period (see the small dots in the left-hand charts of Fig. 1), this subject was evidently able to hold clearly his criteria of sensation strength over the three months during which data were taken. The strong, medium and weak curves show no tendency to rise with increase in size of the stimulator in Sc-44°, but do show such a tendency with Sc-10°. It appears that in Sc-44°, adaptation time is closely related only to strength of initial sensation. In Sc-10°, this is the primary relationship, but some dimensional factor (area, diameter or perimeter) is involved in a secondary fashion.

Subject Al (Fig. 2).—Superficially, the general level of adaptation time and percentage of response in this subject are very similar to those of subject Sc. However, the curves are less irregular and linear relation to diameter more apparent, especially with Al-10°. The right-hand main charts are clearly different from those of subject Sc. There is no sharply defined difference in level of the strong, medium and weak curves with smaller sizes, although some does appear with the larger, especially with Al-44°. With the smaller sizes the curves slope upward, but tend to become more nearly horizontal in the larger sizes.

[4] The subjects were instructed to report cold sensation strength in terms of 1 for weak, 2 for medium and 3 for strong, with intermediate grades if they wished. (*A*, *B* and *C* for warm sensations.) Subject Sc reported all sensations as 1−, 1 or 1+; or as *A*−, *A* or *A*+, with a very occasional 2− or *B*−, and never used the higher numbers. Since, however, three grades are clearly indicated, they have been arbitrarily called weak, medium and strong in the analysis. The other subjects employed the full range of the scale.

Two relationships, then, seem to be involved: (1) the relation of adaptation time to initial strength of sensation, which is relatively more apparent in the larger sizes and probably more marked with 44°; (2) the relation of adaptation time to some dimensional factor (area, diameter, perimeter), which is primary in the smaller sizes and probably stronger with 10° throughout.

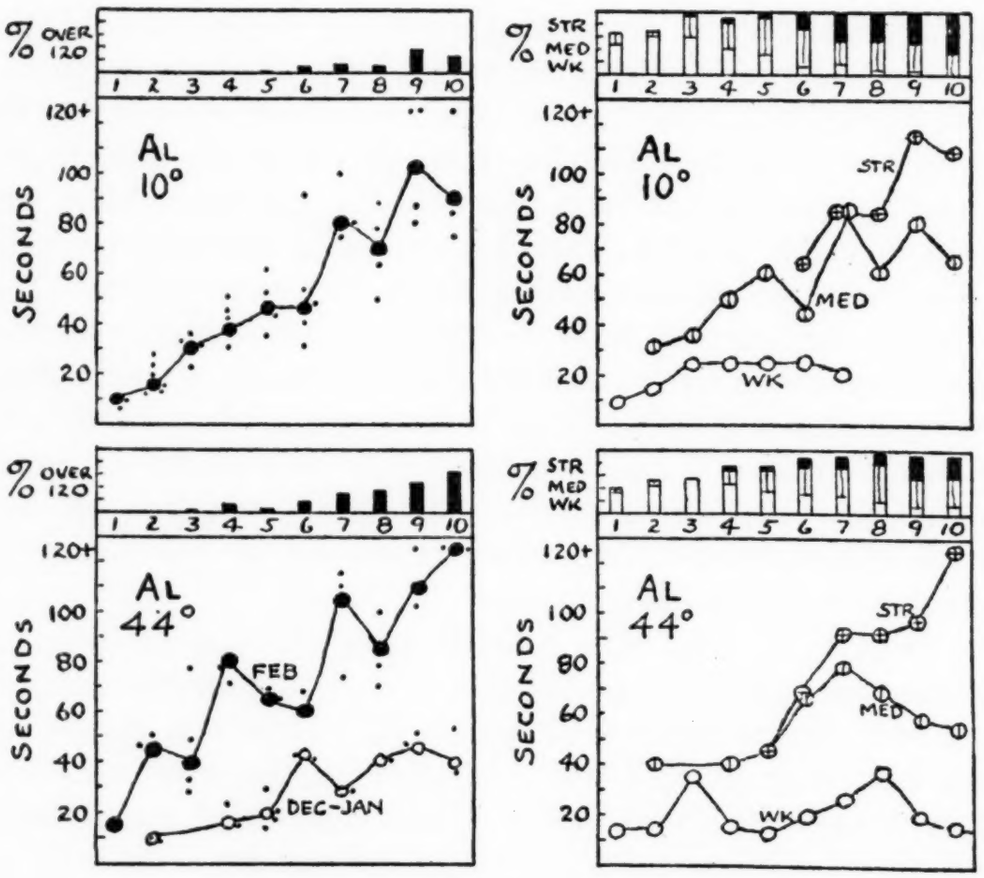


FIG. 2.

Subject De (Fig. 3).—In this subject, both the general level of adaptation time and the percentage of response are lower than with the first two subjects. In De-10° (left-hand chart), the values lie quite regularly in linear relation to diameter; whereas in De-44°, there is too much irregularity for any statement. The right-hand chart for De-10° is strikingly different from that of Sc or even of Al. Not only is there no clear separation of the three curves, but they actually interweave, and all rise with increase in stimulator

size at about the same slope as the general median curve in the left-hand chart. With De-44°, there is some indication of separation with the larger sizes and the 'weak' curve, at least, appears horizontal.

In this subject, then, some dimensional factor (area, diameter, perimeter) appears to be the only relationship with adaptation time in the case of 10° stimulation. With 44°,

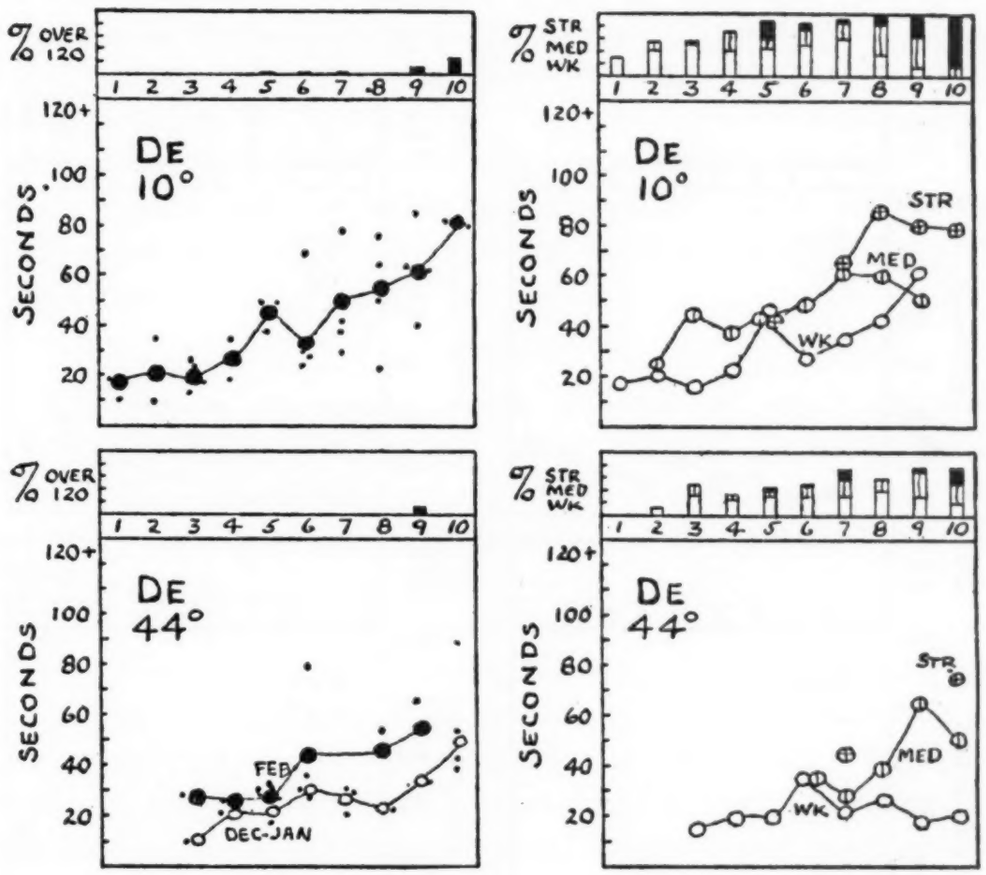


FIG. 3.

this appears to be the primary relationship, although there is some evidence that initial strength of sensation also enters in.

Subject Sm (Fig. 4).—Most striking in this subject are the very low levels of adaptation time and of the percentage of response to 44° stimulation. The latter was almost unbelievably low. The smallest sizes of stimulators were totally ineffective, and even the largest (10 mm diam.) at 44° evoked a response of warmth only half the time! The percentage of response was also highly variable from period to period,

which made the securing of adequate comparative data on the various sizes nearly impossible. We hesitate therefore, to draw any conclusions from the few figures available for warmth. Concerning cold, there appears to be a reasonable separation of the strong, medium and weak curves (considering the low level of all adaptation times) and these are all roughly horizontal. On the face of it, this indicates a relation of adaptation time to initial strength of sensation, with no relation to a dimensional factor of the stimulator as such.

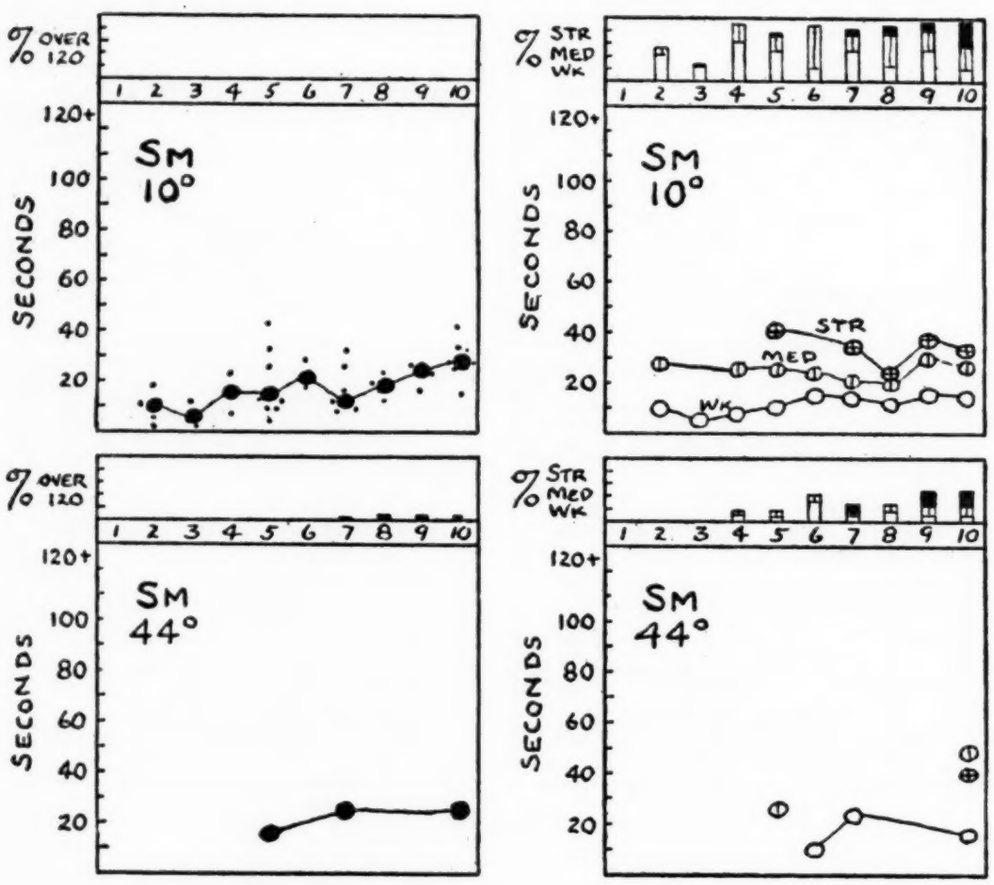


FIG. 4.

DISCUSSION AND CONCLUSIONS

The most interesting feature of the foregoing findings is the suggestion that adaptation time may be correlated with either or both of two factors:

1. The initial strength of sensation, which in itself appears to be a function of the diameter, or more probably, to the square root of the area of the stimulator.

2. Some dimension of the stimulator (area, diameter or perimeter).

The evidence based upon subjective reports indicates that the correlation with these two factors varies in the four subjects. At one extreme, an almost pure correlation with initial strength of sensation is indicated in the case of Sc-44°. At the other extreme, De-10° shows an almost pure correlation with some dimension of the stimulator. However, these results with circular stimulators provide no objective check; since square root of area, diameter and perimeter vary concomitantly.

A critical test would necessitate a series of stimulators in which square root of area and perimeter could be varied independently. This can be accomplished with rectangular stimulators.

Summary

Adaptation phenomena with a series of small circular stimulators ranging from 1¼ to 10 mm in diameter, with temperatures of 10° and 44° C., are reported in this study on the volar surface of the forearm of four male student subjects. The data reveal the possibility that the length of time for complete adaptation may be correlated with either or both of two factors: (1) the initial strength of sensation, itself roughly related to the square root of the area; (2) some dimension of the stimulator, as such, probably the perimeter. Analysis based on subjective reports indicates that these two correlations vary among the four subjects. But circular stimulators provide no objective check, because square root of area and perimeter vary concomitantly. Rectangular stimulators, in which square root of area and perimeter can be varied independently, are suggested as a critical test.

(Manuscript received July 13, 1937)

THE NEURAL DETERMINATION OF CRITICAL FLICKER FREQUENCY[1]

BY S. HOWARD BARTLEY

It is well known that a series of flashes may be the sensory equivalent of continuous light. This is true even when the flashes are brief and separated by relatively long dark intervals. One or more of the current postulations to account for this places the responsibility in the behavior of the photoreceptors of the eye. That is to say, critical flicker frequency is photochemically determined. However, since the nervous system intervenes between photoreception and sensation, the possibility of its determining critical flicker frequency has never been precluded. And recently certain facts have been called to attention to make it very likely that it plays this sort of a role (Bartley, '37).

Continuity must be accomplished by slow recovery somewhere in the active system, so that by the time that the succeeding flash is given, some process will not have slowed down or otherwise changed enough to make an appreciable difference on some later segment in the pathway. If such virtual uniformity occurred in the photoreceptive system, it could then be assumed that when critical flicker frequency is reached, the sense-cell would be firing at a uniform rate, this supposedly being the *sine qua non* of the sensory stationary state. Such a postulation is sufficiently attractive and simple to be quite commonly held today, although it is by no means an established fact. Continuity or uniformity may be accomplished only in a later segment of the pathway.

It is known that the frequency of sense-cell discharge is a function of the intensity of the stimulating light. Records (Hartline, '34) show that the maximum rate at which the limulus sense-cell fires is about 50 per second. We should

[1] From the Laboratory of Neurophysiology, Washington University, School of Medicine, St. Louis. This study was made under a grant from the Rockefeller Foundation for research in neurophysiology.

expect the maximum rate to be greater in the human subject. If it be as great as 200 per second, the shortest interval between discharges would be 5 ms. Under lesser illuminations, the frequency would vary on down to a single discharge per flash with threshold stimulation, where the rate would be that of the flash rate. And we know that flashes may be as low as 3 to 4 per second at absolute threshold and yet produce sensory 'fusion.'

To determine the roles played by photoreception and the neural part of the retina, it must be shown whether the former can react to more rapid changes than the latter.

Manipulating the light-dark ratio (L. D. R.) of the stimulation cycle ought to give us some information both on the velocity of instituting the sense-cell discharge and also on its rate of decay. The light fraction can be made small enough to be within the critical flash duration or long enough to indicate the shortest possible dark interval which will just produce flicker. The first extreme is an indication of the time taken to set up a discharge in the sense-cell (Hartline, l.c.), and the second, the time taken for the dark interval to effectively change sensation.

Method

Since it is difficult to know when critical flash duration is reached with recurrent stimulation in human flicker experiments, certain animal experiments were made prior to them in order to relate critical flash interval (c.f.i.), the reciprocal of critical flicker frequency (1/c.f.f.), to a measure of latency of response to the flashes. The method chosen for doing this was the recording of cortical action potentials in the rabbit. Although a circuitous approach, its convenience and validity have been demonstrated (Bartley, '35, '36). The same L.D.R. variations were used on the animal as were later on the human subjects, and the implicit time of the cortical response was measured, implicit time being the interval between the onset of the flash and the peak of the response wave. That implicit time parallels c.f.i. can be seen from the following. In the animal experiments, the flash interval was made long enough for the appearance of a burst of impulses, summing to give the recorded wave. Manipulating the L.D.R., that is, flash duration, varied its implicit time. In the human experiments, the flash interval was short enough for the bursts correlated with the flashes to be reduced to the vanishing point and be supplanted by relative uniformity of discharge. The difference in the length of the flash interval between appearance and the non-appearance of the bursts (responses) is virtually negligible. It is to be expected that the implicit time of the bursts when they exist is manipulated by the same factors as in the animal experiments. Since the size of the bursts (waves in the records) and their implicit time go hand in hand, the same factors that time the bursts should be those to control

c.f.i. And so we have the justification for using the two sets of results in a parallel fashion in the treatment that is to follow.

Results

In Fig. 1 are two curves showing the relationship of implicit time and the L.D.R. Since the flash rate was kept

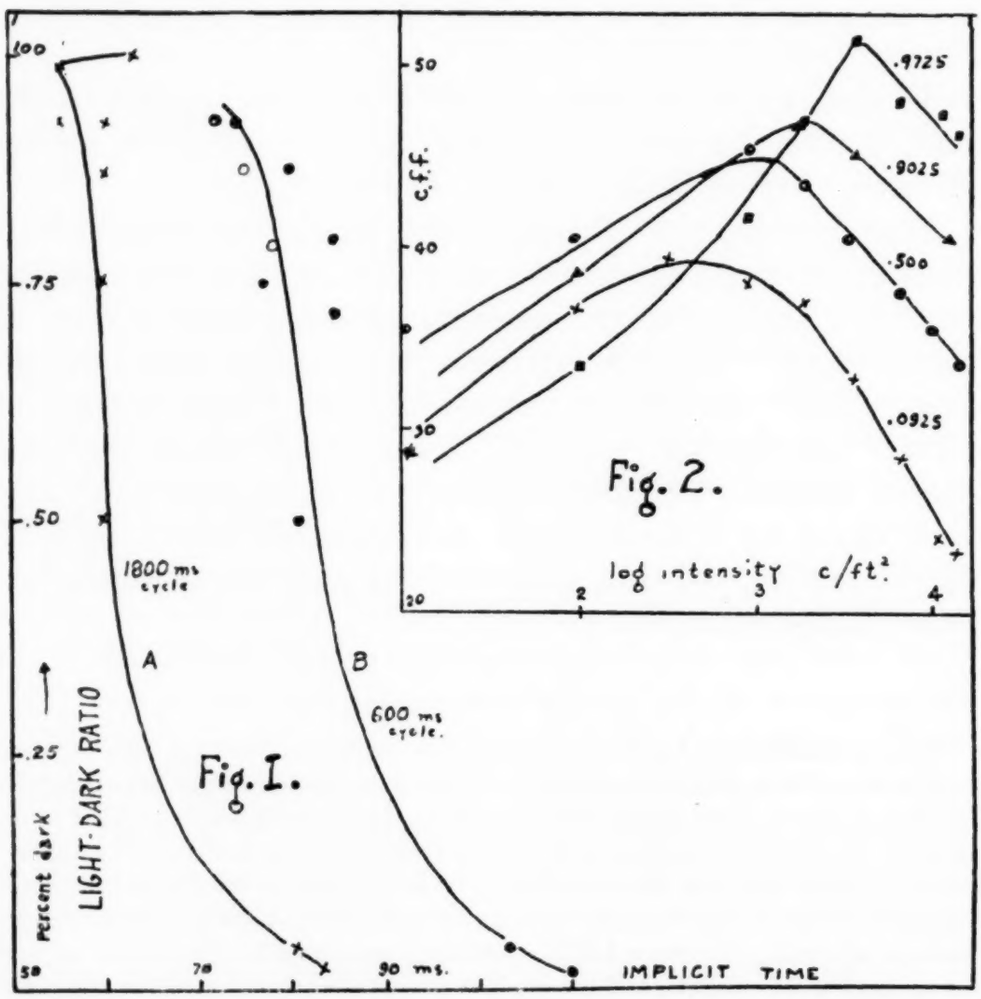


Fig. 1. The relation between light-dark-ratio of the flicker cycle and cortical implicit time.

Fig. 2. The relation between critical flicker frequency and stimulus intensity. From comparable points on each of these curves values were taken to construct the curves in Fig. 3.

constant, they show the relation of flash duration to implicit time, of course, complicated by the factor of recovery, inasmuch as the flashes were given close together. Curve *A* represents a flash interval of 1800 ms, and *B*, 600 ms. Flashes

long enough to occupy most of the interval elicit responses with greater implicit times than do short flashes. However, when they become very short, implicit time begins to lengthen again. The existence of a critical duration below which if flashes are reduced, latency is lengthened has been shown in a number of studies using non-repetitive stimulation (among which are Adrian and Matthews, '27; Bartley, '34). Here we have an example of critical duration with repeated stimulation. For Curve *A*, the probable critical duration is of the order of 9–10 ms, though with the particular apparatus used, we were not able to very accurately measure such short flashes.

Since it is important to know whether the critical duration represented here is the same as for non-repetitive stimulation, certain tests were made under better conditions and with isolated flashes, in which the critical duration for the same intensity of flash was found to be about 10 ms. From this it can be concluded that the inflection in Curve *A* not only represents critical flash duration but the same critical duration as if the flashes were isolated rather than repeated at short intervals.

Figure 2 shows the c.f.f. variations for different flash intensities, each curve for a separate L.D.R. To construct the curves in Fig. 3, points on each of the curves in Fig. 2 for each of four flash intensities were chosen. These c.f.f. values were converted to their reciprocals, that is, to critical flicker intervals, to put them into measures which, as explained above, would parallel implicit time. Thus, Fig. 3 contains four curves showing how L.D.R. and c.f.i. vary, each curve for a separate flash intensity. As might be expected, a fundamental similarity is obvious between the curves in Figs. 1 and 3. Curves *C* and *D* each show the inflection as in Curve *A* in Fig. 1. Thus, Curves *C* and *D* show that critical flash duration for the two lower intensities was reached within the L.D.R. range used. In Curves *E*, *F*, *G* for higher intensities, this did not happen. The flashes were not made short enough. It is certain, however, had they been made a little shorter, critical duration would have been reached. Four our pur-

poses, however, we can call the durations represented by the upper terminations of the curves, critical, since the error involved will not be in our favor.

With all flashes equal to or less than the critical duration, the length of the flash represents the time taken by the photo-

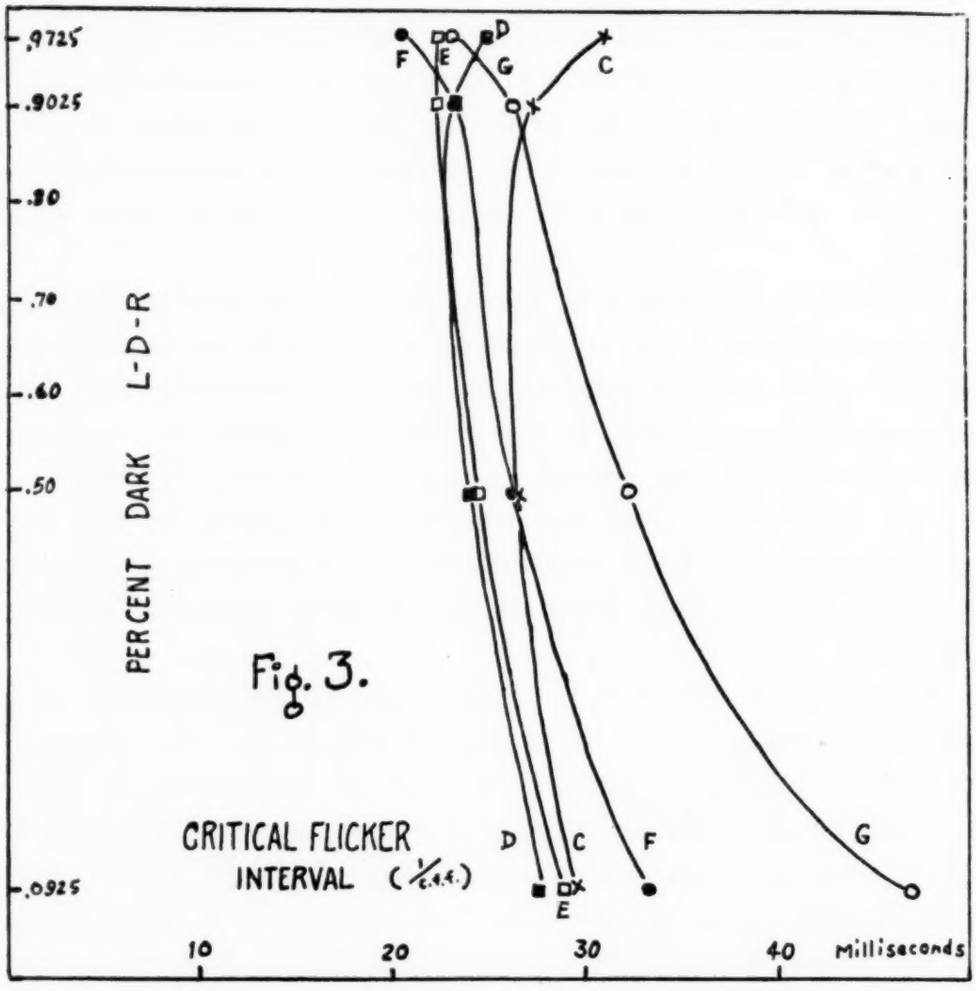


FIG. 3. Relation between light-dark-ratio and the critical flicker interval. (Compare with curves in Fig. 1.)

receptor in instituting the sense-cell discharge, plus a negligible conduction time. Since we are dealing with sensory continuity, critical flash duration is to be defined as the flash duration which for a given intensity produces the minimum c.f.i., and since by implication it designates the time taken to set up sense-cell discharge, it represents the minimum time taken by the photochemical process to do this. In one curve, for

example, the critical flash duration was 0.4 ms and the c.f.i. 20.5 ms. Since such a flash was complete when the sense-cell discharge was set up, the maintenance of sensory continuity was brought about either by the continuence of photochemical activity which keeps the sense-cell firing, or by the maintenance of the necessary activity aroused in the nervous part of the eye set up by only a brief discharge in the sense-cell. The facts outlined so far do not in themselves tell us which it is.

If the lower termination of the same curve (*F*) is examined, it will be seen that when the flash is 0.9075 of the c.f.i., the latter is increased to 32 ms. The part of the c.f.i. occupied by the dark interval is about 3 ms. Of course, if this is increased, either by lengthening the flash interval or by shortening the flash, flicker begins to appear. In other words, if recovery from stimulation here is more than 3 ms, activity apparently changes in some way to provide for flicker. The change, if in sense-cell activity, may be one or both of two kinds. With flashes as long and as intense as these, *off* responses might be instituted when the dark interval is sufficient to permit them, or the dark interval may be long enough to materially change the firing of the sense-cell. If an *off* response occurs, it is probable that it does not happen in the same sense-cell as was discharging to positive stimulation. It has been shown that *on* and *off* responses are set up by separate sense-cells in the scallop *Pecten irradians* (Hartline, '37). If an *off* response is elicited, it is likely that the *on* response also is changed by the short dark interval of a little more than 3 ms. So it is, in a way, immaterial at present whether or not an *off* response occurs, just so long as it can be said that so short an interruption as we found can produce flicker. At least, an interval greater than 3 ms fails to maintain *status quo*. This would seem untenable in light of the fact that we found a 0.4 ms flash producing sensory continuity over a period of 20.5 ms, were we not aware of the two possibilities, namely, the possibility of an *off* response following prolonged flashes, or the possibility of the nervous mechanism of the eye providing for continuity without the uniform rate

of sense-cell discharge throughout the c.f.i., the relationship between sense-cell discharge and nervous retinal activity not being one-to-one. If it requires an *off* response to account for the facts, the question of the role played by the optic pathway beyond the retina is raised. Certain facts are known about the *off* response which may be pertinent here.

It was previously shown that the cortical implicit time of the *off* response was shorter than that of the *on* response (Wang, '34; Bartley, '36) and that an *on* response could follow an *off* response sooner than one *on* response could follow another (Bartley, '36). It was also shown that the *on* and *off* responses varied more or less independently in size from trial to trial. From these facts it seems likely that the two responses are elicited in similar but more or less independent circuits in the optic pathway and in the immediately responding elements of the cortex. If this is so and if the *off* response to long flashes plays a role in flicker near critical flicker frequency, the locus of the first physiological activity responsible for sensory continuity in such cases is removed from the retina to the brain. Thus, photoreception in a simple and direct way cannot be responsible for it. This is equivalent to saying that even though a photochemical system which follows Talbot's Law can be pictured, it does not follow that it is directly responsible for sensations following the same law.

Since the intensity of stimulation (light) and the rate of sense-cell discharge are related, the nature of this discharge is worth some reflection. If evenly spaced at the assumed maximum rate, there would be time for only about 4 discharges during a 20 ms period even if the stimulus continued throughout. With shorter flashes of the same intensity (if longer than critical duration), the discharge rate at the outset would surely be the same as if the light were prolonged. If perceived intensity is dependent on rate, then a short flash of critical duration would be expected to look as bright as a longer one, which is not the case according to Talbot's Law. Sensory intensity must therefore be dependent on other factors than rate at any instant, such as the total number of discharges per unit time and the number of sense-cells firing per

retinal unit. If this be true, then strict uniformity in the discharge rate of each sense-cell is not necessary. Records of discharge in the limulus sense-cell responding to low intensities of continued illumination exhibit this very irregularity.

Conclusions

The items, then, that have been rehearsed lead to the following conclusions: (1) That uniformity of sense-cell discharge during the c.f.i. is not absolutely necessary for sensory uniformity. (Uniformity must involve constant quantity from unit to unit of some longer period which is probably not to be marked off by flash intervals.) (2) That single sense-cell discharges are able to set into motion the necessary nervous activity to bring about sensory continuity over many milliseconds (threshold stimulation). (3) That a very few discharges occurring during the first part of the c.f.i. are sufficient in situations far above threshold where, for example, a flash of critical duration such as 0.4 ms is able to produce a c.f.i. of 20.5 ms. (4) That with flashes occupying most of the c.f.i., flicker is produced when a slight extension of the dark interval probably allows a slight *off* response to occur. (5) That *off* responses probably occur in sense-cells other than those responding to positive stimulation. (6) That if this is so, the primary physiological conditions responsible for sensory "fusion" or uniformity are beyond the retina in such cases.

It is pertinent to add in concluding that the behavior of the electrogram of the retina has suggested that the sensory stationary state is brought about by the nervous part of the eye in the situations tested. The records of Granit and Thurman ('34) showed that a series of similar light flashes can produce unequal sized responses, which Bartley ('37) interpreted in connection with following facts to mean that different functional elements were responding to successive flashes. He found that latency of the responses to a rapid train of flashes was greater than the flash interval and that after flash frequency was raised to about one-half the expected critical flicker frequency, latency which had become longer as fre-

quency was raised, quite quickly shortened again. This suggested that the flashes were given too fast for any unit to respond to successive flashes. Hence, the nervous part of the retina was not able to keep pace with the photochemical and so determined critical flicker frequency.

(Manuscript received June 21, 1937)

References

1. Adrian, E. D. and Matthews, R., Action of light on the eye. Part II. *J. Physiol.*, 1927, **64**, 279–301.
2. Bartley, S. H., The relation of duration and intensity of brief retinal stimulation by light to the electrical response of the optic cortex in the rabbit. *Amer. J. Physiol.*, 1934, **108**, 387–408.
3. Bartley, S. H., The time of occurrence of the cortical response as determined by the area of the stimulus object. *Amer. J. Physiol.*, 1935, **110**, 666–674.
4. Bartley, S. H., A comparison of the electrogram of the optic cortex with that of the retina. *Amer. J. Physiol.*, 1936, **117**, 338–348.
5. Bartley, S. H., Some observations on the organization of the retinal response. *Amer. J. Physiol.* (in press).
6. Granit, R., and Thurman, P. O., Excitation and inhibition in the retina and in the optic nerve. *J. Physiol.*, 1935, **83**, 359–381.
7. Hartline, H. K., Intensity and duration in the excitation of single photoreceptor units. *J. Cell. and Comp. Physiol.*, 1934, **5**, 229–247.
8. Hartline, H. K., The discharge of impulses in the optic nerve fibres of the eye of Pecten Irradians. *Proc. Amer. Physiol. Soc.*, 1937.
9. Wang, G. H., Action potentials of the visual cortex and the superior colliculus induced by stimulation of the retina with light. *Chin. J. Physiol.*, 1934, **8**, 121–143.

THE PSYCHOLOGICAL LABORATORY AT THE UNIVERSITY OF IOWA

BY CHRISTIAN A. RUCKMICK

The psychological laboratory at the University of Iowa passed through several transitional stages. As early as 1887 G. T. W. Patrick brought from Johns Hopkins the spitit of experimental psychology and began to use scientific apparatus as demonstrations in his lectures on experimental psychology. He was assigned a large lecture room in the northeast corner of the first floor of Old Capitol. The description of the course has historical significance: "Experimental Psychology, including an introductory study of the nervous system: relation of stimulus to sensation; time relations of mental phenomena; localization of cerebral function, three hours, one term." By 1890–91 this course was re-labeled 'Advanced Psychology' and was described as laboratory work in psychophysics, time relations of mental phenomena, *etc.*, with Ladd's *Outlines of Physiological Psychology* (1887) as the text. In 1892–93 this course was extended to two terms, five times per week and James' *Principles of Psychology* became the text. At that time the lecture and demonstration room was moved to the southeast corner of Old Capitol, on the same floor, where the secretaries to the president of the university now function.[1]

In the early years apparatus was scarce, but then there was apparatus. Dr. Patrick ordered from Germany during the second year a set of six tuning forks mounted on resonators, and a large dissectible model of the human brain, together with other models of the brain, of the ear, and of the eye. There were also many charts of the nervous system, special senses, illusions, *etc.* The university catalog of 1890–91 gives the following description of the 'Psychophysical Laboratory.'

[1] Dr. Patrick observes that "my class . . . was somewhat startled by the appearance of a sheep's brain on my desk. A few of the students met with me to dissect it." *Iowa J. of History & Politics*, 1932, 30, p. 412.

"The Psychophysical Laboratory is designed for the experimental study of psychology. Only a beginning has been made thus far, but at present apparatus is provided for testing the psychophysic law, for the measurement of reaction times, for testing color blindness, for mixing colors by rotating discs and for exhibiting the structure of the brain and nervous system."

During 1892–93 the laboratory was moved to the lower floor of a brick building on Clinton Street which formerly had housed the Homeopathic Medical Department. Here there was a large lecture room, a seminar and reading room, and three laboratory rooms. The description of apparatus at this time is significant:

"The present equipment of apparatus is as follows: Fifty wall charts illustrating nervous system, special senses, illusions, etc.; Anzoux's dissectible model of the brain; five Steger models of the brain, ear, and brain of orang-outang; rotation apparatus, with sets of disks for illustrating mixing of colors and color contrast (from Krille); set of six tuning forks with resonance boxes, for illustrating harmony, beats, sympathetic vibration; Hipp chronoscope with electrical connections, two reaction keys and one five-finger reaction key; instantaneous exposure apparatus; tachistoscope (after Wundt's model); series of 22 Koenig cylinders for highest audible note; æsthesiometers; brass cylinders, for demonstration of heat and cold spots; metronome; dark box; small rotation apparatus; loaded boxes for testing psychophysic law; sound pendulum (by Krille); apparatus for testing color-blindness; minor pieces for miscellaneous use." [2]

After these early beginnings the laboratory was given more commodious quarters in the new Liberal Arts Building (Shaeffer Hall) in 1899. For the first time a laboratory was built according to the specifications of the director of research. Some 4,500 square feet of floor space was planned to meet the needs of the department.[3] Of particular importance was the construction of a sound-proof room set on an independent foundation in sand-boxes and making no direct contacts with any of the walls of the building. At first the unit comprised one large and one small lecture-room, a room for storing apparatus, a work-shop, five laboratory research rooms, two offices, and a library and seminar room. Other small rooms were added from time to time as research projects developed.

In the course of further development, a separate Child Welfare Research Station with a number of independent laboratories and facilities for research had been organized in

[2] *Ibid.*, p. 413–414.

[3] G. T. W. Patrick, A New Psychological Laboratory of the University of Iowa, *Univ. Iowa Stud. in Psychol.*, 1902, 3, 140–144.

1917 and a Psychological and Speech Clinic had been established in 1920 in the Psychopathic Hospital with additional rooms and equipment designed primarily for electrical investigations in the neuro-physiological field and for testing the intelligence of patients and for the psychometric procedures.

Gradually the main laboratory became overcrowded with apparatus and research work so that when the old hospital building consisting of over 300 rooms was remodelled, the department of psychology was permitted to take over a portion of it consisting approximately of the ground and first two floors of the east wing and the first two floors of the central section with overlapping interests in the area of research concerning speech and phonetics in other parts of the building. The new laboratory at East Hall was dedicated on December 30, 1930, during the 38th annual meeting of the American Psychological Association at Iowa City.

The laboratory, as it is now constituted, consists of about 85 research rooms, not including ten rooms used primarily as offices. Many of these rooms are of the usual hospital private-room size, 12′ × 12′, although a number of them have been repartitioned to suit our needs. What had been larger ward units in the old hospital building were transformed into lecture rooms (E104, E105) each seating about 120 persons, the latter room being especially equipped with a standard demonstration table that is supplied with water, gas, compressed air and the several different types of electrical current with which the entire laboratory is furnished. There are also four classrooms and a seminar room for smaller units. Other classrooms are to be found on the third floor (not shown) of the east wing.

A number of research rooms are designed for special purposes. There are four darkrooms for general use (E122, 123, 221, 222), besides the three sound-proofed rooms (C215A, C209), the photographic darkroom (E7) and the acoustical recording room (south of E6). Several other rooms can be darkened by means of black curtains running behind hinged slats (C207, C209C, C209D, and C211). Room C207 is used for the projection of motion pictures with a partition contain-

ing double glass windows separating the projector from the theater. E1 is fully equipped for operating on animals, E2 is assigned to the electrical technician, E3 is reserved for electrical research and shop-work, E4 is the electro-encephalographic research room, E5 is the general workshop, E6 is the acoustic research laboratory, and E8 is the kymograph room. E6, E104 and E105 are acoustically treated partially to eliminate reverberation.

The sound-proof room in the former laboratory, which has been described in detail elsewhere[4] is still intact and is available for use, but since connection with the rest of the laboratory in East Hall is practically out of the question, actually it can be utilized only for isolated experiments. Our main sound-proof room (C215A) was built according to the writer's specifications as a cubicle within a special enclosure which used to be one of the obstetrical operating rooms and which was therefor originally built as a separate unit with walls 14″ thick on the side toward the main hall and 7″ thick on the other three sides. The floor was heavily tiled. Within this space of 20′ × 12′ × 11½′ a room was constructed with inside dimensions of 14½′ × 8′ × 7½′, set upon cork piers. Originally helical springs were specified for the foundations but these could not be conveniently obtained. The walls, ceiling and floor are 7½″ thick with a 2″ air-space added on the inside of the walls and ceiling which is covered by a heavy black felt, hung in folds and nailed on strips. On the outside the room is covered with celotex, then by a galvanised iron sheeting which completely surrounds the room, not only as a reflecting surface, but as an electrically grounded shield. This is followed by two thicknesses of celotex, a dead air-space and again two sheets of celotex. The door is of the ice-box type constructed in the same way as are the walls and ceiling. The outside door is also lined with celotex. On the floor is an additional layer of 'battleship' linoleum. On that account and because of the presence of tables and chairs in the room, the room is only partially deadened, but it is effective as a sound-proofed room. The three cardinal principles of sound-

[4] *University of Iowa Studies in Psychology*, 3, 1903, p. 142.

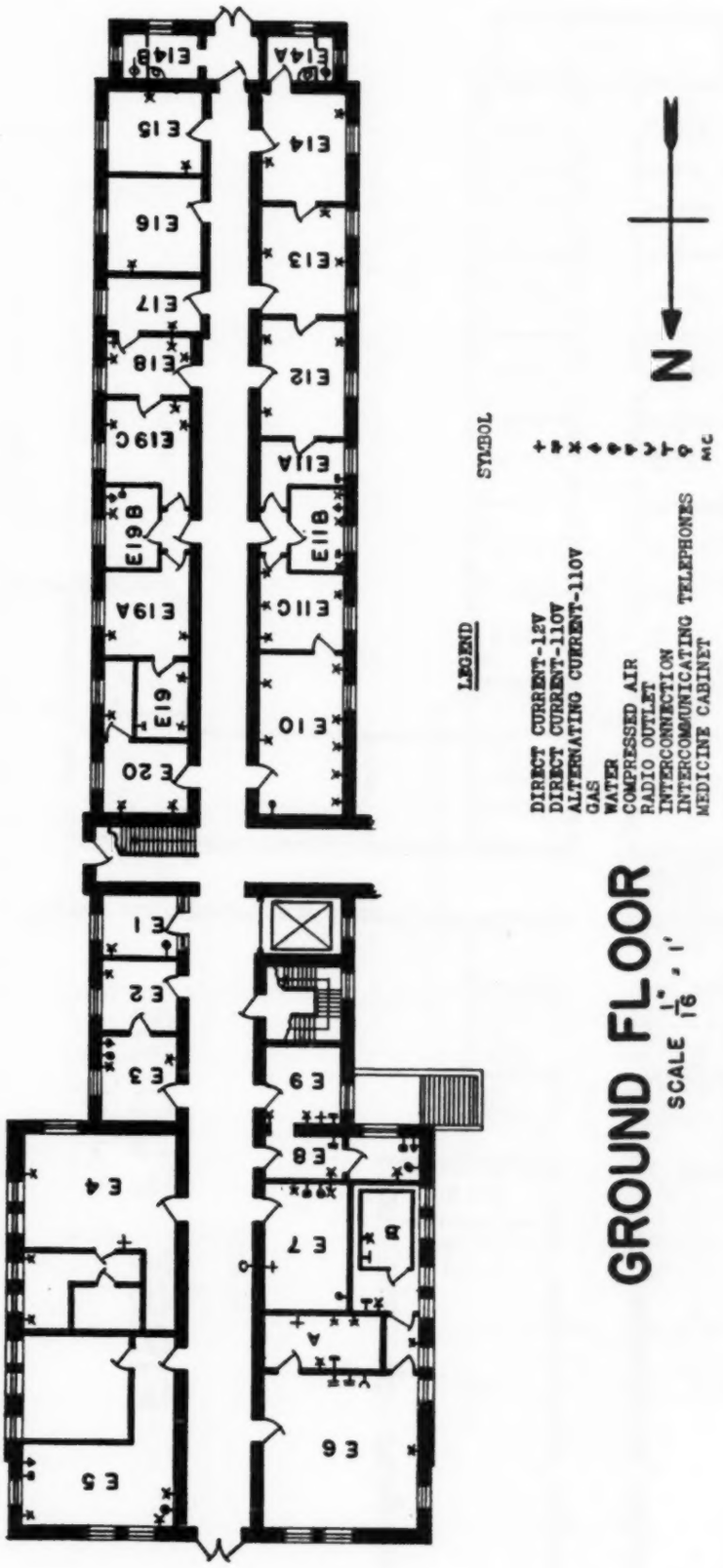
proofing have been used, *viz.*, absorption of sound vibration which reaches the room, reflection of whatever amount of sound vibration that remains, and non-conduction of sound vibration from other parts of the building. Traffic in the halls and sounds in the building can be further blocked by closing doors in various parts of the surrounding halls. Service wires which enter the room are coiled to avoid conduction. The ventilating shaft through which air is sucked out of the room by a large fan in the attic, two floors above, is constructed of loosely wound burlap and heavy floor felt. The floors in this part of the building are 15″ thick and are covered with linoleum cement on the upper surface and sheet iron on the ceiling surfaces in the main hallways. The other sound-proofed room (C209A) needs no special specification since it has only a layer of celotex on the inside and is not built as a separate cubicle. It serves as a chamber for the housing of special instruments, like audiometers, in connection with the sound-proofed room just described.

On the ground floor southwest of E6 and leading off from it is the 'dead' room (E6B) in which many of the acoustical investigations are carried out. It is intricately connected electrically with E6, especially with the recording room leading off directly south of that room (E6A). These three rooms centering around E6 and including E8 and E9 are an integral unit of the section devoted to acoustical research and contain elaborate modern apparatus for this purpose. The 'dead' room was constructed according to specifications of acoustical engineers from the Johns Manville Co. It measures $14' \times 8\frac{1}{2}' \times 8\frac{1}{2}'$ approximately, because, to avoid reverberation, no two surfaces are exactly parallel to each other. The walls, floor and ceiling are covered on the inside with large wire mesh, muslin, and a thick layer of rock-wool. On the outside the room, built as a cubicle within the permanent walls of the outer enclosure, is covered with celotex. It stands directly on the cement floor of the laboratory. Sound-proofing was not especially aimed at, but since it is recessed in a relatively quiet section of the laboratory, few disturbing sounds do, as a matter of fact, enter the cubicle. The oscillo-

grams taken from recorded speech and music actually show no disturbances of this sort.

The rooms surrounding E4, the electro-encephalographic research laboratory, (E1, E2, E3 and part of E5) serve as the unit within which the so-called 'brain-wave' technique is applied to the lower animals and to man. In the northern section of E4 is a room constructed of copper mesh wire and studs for the purpose of electrically shielding the subject. In E4 are the control and recording instruments for this purpose. Rooms E10 to E20 serve as the speech and psychological clinic. On the floor above rooms E101, E103 and E106 to E127 serve as research quarters for advanced investigations in the areas of music, reading and speech. The eye-movement camera, useful for investigations in reading, art and advertising and other fields is stationed in E206. The Henrici harmonic analyser is located in E120. On the second floor rooms E201 to E203 and rooms E207 to E226 are also devoted to advanced problems, but of these rooms E208 to E226 are primarily designed for the laboratory classes in intermediate drill experimentation, with the exception of E209 which is the storage battery room. Here is the Exide EMGO AC Floating Battery System of six 2v. cells of 224 amp. hr. capacity delivering a maximum of 12v. to most of the laboratory rooms through a simplified panel-board operating on the principle of cross-bars and plugs. The cells may be charged quickly by means of connections to the 110v. DC line current, stepped down through heavy duty resistors, or more slowly by means of a Tungar charger.

In the central section of the laboratory on the second floor is included the research rooms that are primarily devoted to the psychology of art (C201, C203, C204, C208 and C211 to C215) and those rooms that serve research in the area of feeling and emotion with particular reference to the electrodermal response (C207, C209, C209A, C209B, C209D and C215A). Rooms C207, C209A, C211 and C215A are all interconnected electrically with 24 double electrical circuits and four circuits for high-tension current. In room C211, these circuits are all brought together for attachment of apparatus and for re-


E14B
E14A
E15
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E19C
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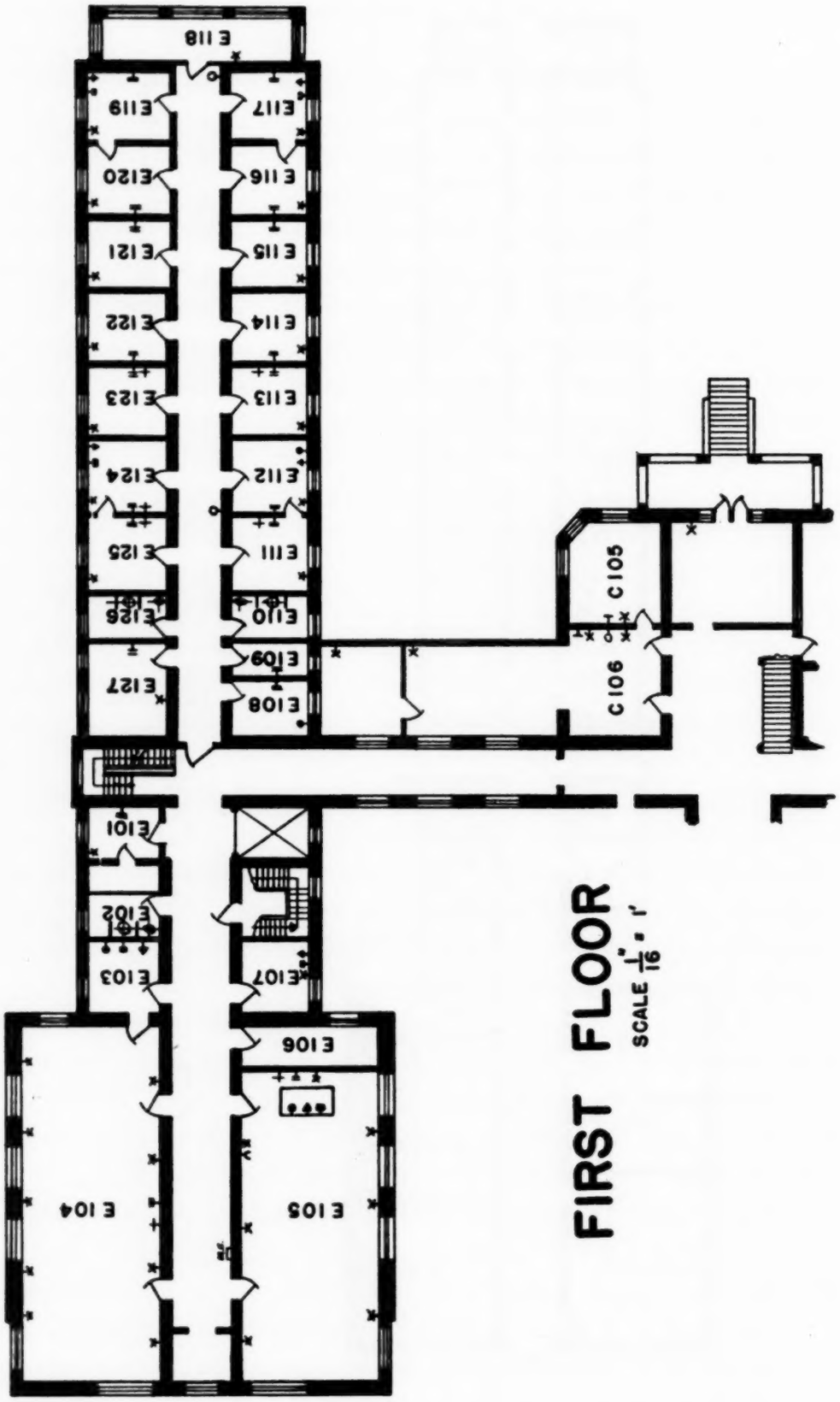
E5
E6
N
LEGEND
SYMBOL
DIRECT CURRENT-12V
DIRECT CURRENT-110V
ALTERNATING CURRENT-110V
GAS
WATER
COMPRESSED AIR
RADIO OUTLET
INTERCONNECTION
INTERCOMMUNICATING TELEPHONES
MEDICINE CABINET
MC
GROUND FLOOR
SCALE 1/16" = 1'


E118
E119
E117
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E121
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E126
E110
E127
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C106
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E102
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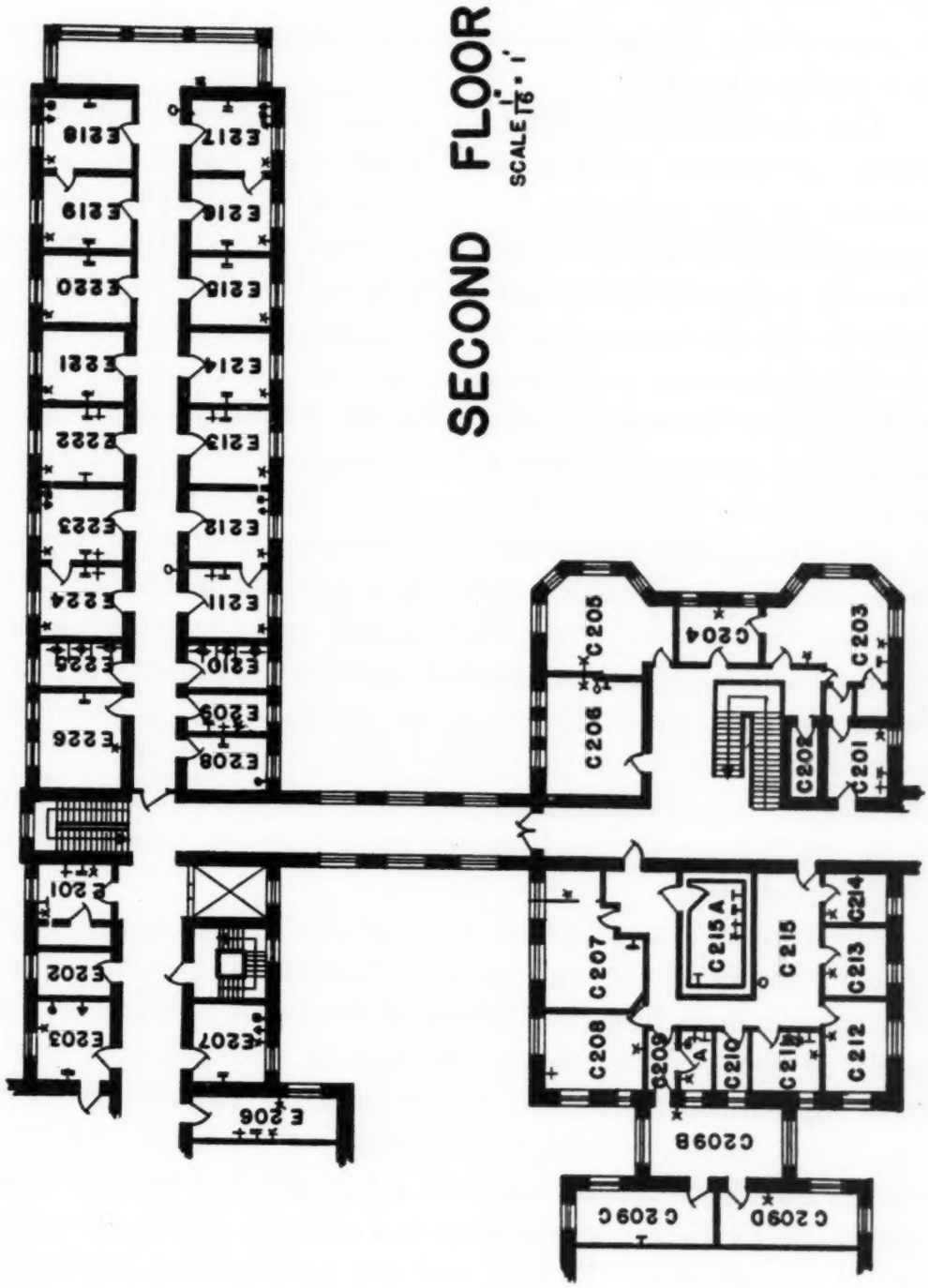
E107
E106
E104
E105
FIRST FLOOR
SCALE 1/16" = 1'


SECOND FLOOR
SCALE 1/16" = 1'
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E203
E217
E216
E215
E214
E213
E212
E211
E210
E209
E208
E207
E206
C205
C204
C203
C206
C202
C201
C207
C215A
C215
C214
C213
C208
C209
C210
C211
C212
C209B
C209C
C209D

distribution. To the unit in the psychology of art should be added two rooms in the east wing, E409, a studio, and E414 into which the creative composition apparatus is incorporated. Room C205 in the central section was designed as a seminar room.

The distribution of different types of services, like electricity of various voltages and types, gas, water and compressed air are indicated by symbols as interpreted in the legend which is attached to the ground floor plan. Where the solid walls are indicated as broken, 2″ iron tubes have been built in for the passage of rubber tubing, electric wires and the like from room to room, as in the case, for example, of the wall between E222 and E223. To list the separate pieces of apparatus, as was the custom in articles of this sort long ago, would unduly lengthen the account. Suffice it to say that in all of the units mentioned the most modern and accurate instruments are available for specified research in these sectors. New pieces are being constantly added and a spirit of inventiveness and adaptation provides new developments in each field. An expert machinist is at the service of the department for two days each week in a fully equipped shop in the Physics Building. In an additional shop next to the main machine shop, students may work under his advice to make and to adapt apparatus.

We should also say that an attitude of real cooperation prevails between the various departments and divisions on the campus including the College of Medicine. Without this spirit of cooperation, much intellectual and physical waste and duplication of effort would result. Psychology now touches so many different disciplines at so many different points, that both inspiration and aid in the exchange of ideas and in the furnishing materials are a *sine qua non* in the progress of our science. To that end the motto which motivates our research is excellently inscribed in the framed dedicatory plaque which hangs in the main hall of the laboratory, where also hang the autographed portraits of distinguished living psychologists, of doctorate graduates, and several series of

portraits of psychologists and philosophers who have contributed historically to psychology. This motto reads:

Insight into the Nature of Mental Life,
Appreciation of its Beauty, and
Wisdom in its Control

Development of Personality, Scientific Integrity,
and the Art of Deliberate and Adequate
Statement of Fact

Center for Fundamental Science and
Service to Mankind

Memorial to the Pioneers in Psychology
Hearth for Comrades in Research

To these Ends this Laboratory is Solemnly
Dedicated for the Commonwealth of Iowa

(Manuscript received October 4, 1937)

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